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MODELING STRUCTURAL CHANGE USING EARLY SOVIET DATA*

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This paper describes a multi-sector, multi-period, economy-wide model constructed by applying linear programming techniques to an input–output system. The model is designed to provide a flexible, cost-effective tool for testing the impact of alternative development policies on consumption levels, capital stocks, output growth rates, and rate of technological change. Early Soviet data are used to show how the model can generate a problem-free expansion path as a reference. The model and reference solution are then used to decompose historical experience, measuring the intersectoral and intertemporal impact of major historical events on the economy's performance.

1. Introduction

Most development planning is future-oriented, but in this project an economic development model is used to study Soviet experience in the 1930s. An exercise in ex-post planning is justified by the availability of a substantial volume of reasonably accurate data, and by the historic importance of Soviet pioneering efforts. Soviet planning agencies had by 1929 assembled data which in volume and detail would be the envy of most developing nations today. The Soviet industrialization drive launched in 1929 was the first massive effort to restructure an economy and that experience is rich in lessons. Our model is designed to permit systematic investigation of alternative expansion paths so that we may compare the actual record with hypothetical alternatives.

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The present paper focuses on the model itself: the considerations influencing its design, its structure, and the properties that may prove interesting to development economists quite uninvolved with Soviet studies. While preliminary results are summarized, other papers provide greater detail on the findings that emerge from applying KAPROST (from 'capital growth' in Russian) to the Soviet record.[1]

2. The model

The model is constructed from an input–output system of ten producing sectors and six categories of final demand. This is converted from a static to a dynamic framework by linking current investment expenditures to future capital stock increments. The system is then driven through time by a linear programming algorithm which is guided by an objective function including each period's consumption and the post-terminal period capital stock. The model is a straightforward extension of that developed by Eckaus and Parikh for their study of India's five year plans.[2]

Several extensions of the model are necessary to adapt it to Soviet purposes and procedures of the 1930s. Most notably, two technologies are available for each producing sector in each period, limited by the capital stock in that sector. The old technology is embodied in the stock of fixed capital inherited from the pre-1929 period. Capital built after this time embodies the new, advanced technology.[3] Second, not only are peasants (agricultural labor) and workers (non-agricultural labor) assumed to have different consumption behavior, but a policy parameter is included to allow government-imposed belt tightening through lower consumption/income ratios. Third, newly-completed fixed capital is operated at less than full capacity until its intricacies have been mastered.

We put terminal year capital stocks into the objective function,[4] along with worker and peasant consumption, so that manipulation of weights can reflect alternative policy emphases. Placing capital stocks in the objective function not only supports future consumption indirectly, but also supports expansion of other forms of final demand as well. The USSR, like many developing nations today, attached very high priority to building up the economy's stocks of fixed capital, especially in heavy industry, as a base for national power. Moreover ongoing growth rests on continuous accumulation and therefore a high share of investment in final demand.

In each time period a production accounting relationship requires that intermediate plus final demand uses be less than or equal to domestic gross

[1]See Hunter (1973, 1976), and Hunter and Rutan (1980).

[2]See Eckaus and Parikh (1968).

[3]This approach extends to all producing sectors the option available for agriculture in the Eckaus and Parikh Guidepath Model; see Eckaus and Parikh (1968, p. 156).

[4]Eckaus and Manne suggested this. Bruno et al. (1970) describe a similar objective function.

output plus imports for each producing sector. Domestic gross output is limited by existing capital stock and labour force through fixed productivity ratios. These ratios vary by the technology embodied in the capital stock: old technology output/capital ratios are higher, output/labor ratios lower, than for new technology.

Capital accounting relationships in the model follow the Eckaus-Parikh precedent. Current investment is linked to future capacity increments via capital gestation matrices which reflect the time required to construct buildings and equipment for each producing sector. Soviet plans focused on introducing new technology, therefore KAPROST has a capital gestation matrix for advanced technology only. (The model is easily extended to allow investment in both technologies for researchers studying situations different from ours.) Old capital — the 1928 stock — simply depreciates at rates specified by sector. The labour force is assigned to the capital stock by the linear-programming solution algorithm, shifting from old to new technology capital as the latter becomes available. An additional parameter is inserted to capture the process of 'mastering technique' that was much stressed in the USSR during this period.[5] As new fixed capital comes on stream it initially operates appreciably below designed capacity until the enterprise learns how to use it. We distinguish between 'available' and 'utilizable' fixed capital, the latter being seven-tenths of the former during a two-year learning period.

The aggregate rate of technological change in any sector depends, then, on four things: the rate of depreciation of old technology capital stock, the rate of investment in new technology capital stock, the mastering of new technology capital stock, and the pressure on that sector to deliver output. Technological change is discrete, in that the two production technologies are different, but the rate of technological change is continuous, since investment in advanced technology capital and the use of labor in advanced technology production, as determined in each solution, gradually transform the economy. One interpretation of our two-technology approach is that of an enterprise where old and new capital are often mixed together, even to the extent that new components can be grafted onto old machines. In each sector, in each time period, a composite technology is available, where the weights defining the composite are restricted by the embodiment of technology in the stock of fixed capital.

In the W. Arthur Lewis tradition, Eckaus and Parikh focused on capital as the binding constraint for India, and 50 years ago capital was certainly far more limiting than labor in the USSR. Nevertheless labor productivities in each sector and each technology concerned Soviet planners, and the total Soviet labor force was finite. This model therefore limits aggregate employment as determined by sectoral output and output/labor ratios to the

[5]Derived directly from the absorptive capacity constraint proposed in Eckaus (1973).

total labor supply in each period. Labor can move from one sector to another and one technology to another, but as capital is constrained to be sector-specific, there is the possibility in each period of unemployed labor, unemployed capital, or both.

Consumption and income relationships in the model are designed to facilitate the imposition of key political policy decisions. The usual consumption column in final demand for each period is subdivided, one for the urban proletariat and the other for the rural peasantry. Soviet data were cast in these terms. Peasant incomes are earned in agriculture; workers earn income in non-agriculture; in each case equal to sectoral employment multiplied by each sector's wage rate. Consumption is linked to labor earnings via average consumption/income ratios, one set for workers and another for peasants. In this way the consumption columns and labor rows of each period's flow table are related by a parameter that can be varied in experiments to reflect alternative policies. One could assume tighter belts for the peasants in period two, for example, by lowering their consumption/income ratio. The sectoral composition of consumption is the sum of deliveries in fixed sectoral proportions, based on consumption structure vectors for peasants and workers from actual 1928 and intended 1933 consumption, and optional consumption deliveries from sectors with available output. The shares of fixed-proportion and optimal consumption in any year are determined by additional policy parameters which reflect how much popular preferences (assumed to be embodied in the consumption structure vectors) or planners' preferences (in the form of output availability) should be allowed to dominate.

The treatment of imports and the balance of payments follows the Eckaus–Parikh approach. Imports are divided into two categories: modest quantities required per unit of gross output, and optional amounts as export earnings allow and sector demands suggest. Imports are constrained by export earnings plus an exogenously-specified lump sum amount reflecting external credits, aid, or debt. In Soviet experience these exports could not easily be spared, nor were credits easily obtained. The imports, especially those embodying advanced technology, were in a sense crucial for the whole expansion process, but they were relatively small compared to domestic production, even in the heavy industry sector.

Initial conditions for the model were easy to specify on the basis of ample statistical estimates assembled by the State Planning Commission. Their estimates covered not only available capital stocks at the beginning of 1928 but also the capital-in-progress that came into operation during 1928 or later. Terminal conditions must also be set so as to prevent the solution algorithm from taking an 'après moi, le déluge' attitude toward time periods beyond those covered by the model. After some experimentation, we found that requiring capital formation to continue at the average rate observed over the model horizon plus an exogenously specified growth rate would maintain deliveries to fixed investment at suitable levels.

The appendix below presents the model equations explicitly.

3. Special features of the model

Two features of a model designed like KAPROST deserve special emphasis because they greatly simplify matters for the researcher. First, the seemingly facile dichotomy of old and new technology provides for a quite complex treatment of technological change. Second, by explicitly inserting policy parameters in key linkages, the researcher can easily control a large structure with a few levers.

Each technology is defined by an input–output coefficient matrix, output/capital and output/labor ratios for each sector, and required-import and inventory coefficient vectors (these last are of minor importance in KAPROST). Each technology is embodied in capital stock. Therefore the model realistically allows input–output coefficients to change as advanced-technology capital comes into use. Interindustry relationships are neither assumed to remain fixed over time nor assumed to change smoothly along some specified path. Change reflects the simultaneous gradual disappearance of old capital and emergence of new capital; technological progress issues as a composite result.

This approach also allows capital/output ratios and labor productivity ratios to change over time as capital stocks change. In each sector the growing stock of advanced technology capital and the depreciating stock of old technology capital together generate composite productivity ratios that realistically change as modernization occurs. It is not implausible to attribute the economy-wide composite results to individual plants, where productivities change as advanced technology comes into use.

Overall, the KAPROST model moves asymptotically from a state of all old technology to all new technology activity. The rate of change depends on the rate of depreciation and the rate of investment — as one would expect.

The model can be controlled through three sets of parameters: the weights in the objective function, the average consumption/income ratios, and the fixed-share/optional-consumption proportions. The objective function permits convenient testing of alternative political and social policies. Consumption levels in each period can be raised or lowered through varying the weights assigned to consumption terms for, respectively, urban workers or rural peasants. Terminal-year amounts of fixed capital, sector by sector, can be raised or lowered through varying the weights assigned to them in the objective function. The central issue in purposive development planning — at what maximum acceptable rate can capital accumulation occur? — can thus be explicitly confronted. Trade offs can be estimated and displayed.

The consumption parameters allow the necessary fine tuning which would ordinarily be done through manipulating sector-specific wage rates together with the sectoral pattern of consumption. As this latter set must be defined for each sector and period, whereas our consumption parameters are defined only by period, this means for KAPROST a ten-fold reduction in control parameters!

Following Taylor's advice, we have avoided introducing artificial constraints.[6] Our dual valuations thus convey undistorted though highly aggregated indications of economy-wide scarcity relations. Shadow prices on input constraints are not contaminated by artificial floors or ceilings placed on consumption.[7] High shadow prices in model solutions identify bottlenecks and direct attention to hypothetical changes (ex post) or corrective steps (ex ante) that could relieve the situation.

Through parametric programming variations, one can use this model to feel out the contours of the economy's intersectoral and intertemporal structure. Dual valuations not only identify bottlenecks but also measure the benefits that would result from relaxing them. One can estimate the impacts throughout the economy and over time of any assumed change in the structural parameters: the capital gestation period, the learning parameter, capital productivities, labor productivities, or export–import relations. With respect to all these familiar aspects of economy-wide programming analysis, one can examine the opportunities and limitations present in past examples of economic development, testing the observed interaction between policy and performance.

4. Deriving model parameters from Soviet data

The data necessary for implementation of this model can be derived from the ample statistics compiled by the USSR State Planning Commission and the Central Administration for National Accounts. It is quite clear that these were not yet being distorted by all the pressures that made Soviet statistics so unreliable in later years. Detailed documentation for sources and estimation procedures is available on request.[8]

A sectoral breakdown appropriate to this time and place involves less detail for industry than is often found in current development studies, in order to make room for other sectors deserving attention. Agriculture is divided into field crops and livestock products. Industry is divided into producer goods and consumer goods, with a separate account for electric

[6]See the discussion of type 1, type 2, and type 3 constraints in Taylor (1975, esp. pp. 59–60 and 82–91).

[7]The required average consumption ratios are not artificial constraints as some relation between labor and reward is required in any society.

[8]Write to Holland Hunter, Department of Economics, Haverford College, Haverford, PA 19041.

power, the sector given highest priority by Lenin. Transportation and communication form an important sector, as does construction. Housing services form a sector because residential capital constituted some thirty-six percent of Soviet fixed capital in 1928, and policy towards this sector has been an important aspect of Soviet experience ever since. A small trade and distribution sector is also identified as a non-negligible user of labor and capital. Production of government services (education, health care, municipal services, administration and justice, national defense) also drew appreciably on the economy's resources. These services deserve to have a column in the interindustry and value added quadrants, even if they deliver only to final demand, precisely because they make significant claims on capital, labor, and intermediate inputs. Making government services a producing sector fits Soviet institutions, and also facilitates the modeling of Soviet preparations for World War II.

Within this framework, we wish to measure the expansion potential of the Soviet economy, starting from its 1928 base, as it invested in advanced technology and drew on all the other opportunities perceived by Gosplan and incorporated in the first Five-Year Plan. The plan was overambitious, in that five years was too short a period for accomplishing all objectives, even given the plan's optimistic parameters. We can, however, unhook these targets from the year 1933 and let them shape a more gradual transformation of the economy along intended lines. For this purpose we need, first, to measure the properties of the base-period 1928 economy, and then to derive from the first Plan's 1933 targets the distinct set of characteristics associated with the new technology.

The performance parameters of the old technology have been derived from meticulous Soviet base period estimates for the year 1928. A reconstructed flow table, along with sectoral data for capital stocks and labor force, permits calculation of interindustry coefficients, capital productivities, labor productivities, consumption patterns, required-import ratios, inventory/output ratios, and a base period pattern for export demands and deliveries to government. A comparable flow table and associated set of data for capital and labor have been derived from the targets established in the first Soviet Five Year Plan for the terminal year 1932–1933.

However, these ambitious targets incorporated the old technology capital stock remaining after depreciation, not simply the new fixed capital that would operate with advanced technical characteristics. Together they would produce the intended output. The undepreciated 1928 capital stock, operating with 1928 capital productivities, labor productivities, and interindustry coefficients, would have generated a specific level of gross output, using intermediate goods, labor and imports. Subtracting these values from the first Five Year Plan targets produces the flows due solely to new technology, and from which the intended advanced-technology coefficients can be derived. These new parameters, in turn, can be detached from that specific date to stand as properties of a new economic structure to be constructed through ongoing investment.

Some further revisions to these numbers were required for the first two periods. The initial estimates for fixed capital stocks and capital productivities did not allow some sectors to attain the observed levels of output that were reached in the great surge of activity marking the years 1929–1932. We raised the estimate of both new fixed capital in process and the output–capital ratios for these years just enough to allow each sector to operate at historic levels. Note that the economy was still required to deliver investment goods to complete capital in progress, and that the output–capital ratios for the last four periods were kept at their initially calculated values.

5. A reference solution for the Soviet Union, 1928–1940

A detailed discussion of the development of the problem-free reference solution presented here, together with a display of alternatives, is available in the report by Hunter and Rutan.[9] The solution reflects an effort to maintain consumption at or above 1928 levels while building a large stock of fixed capital by the end of 1940. These were the goals of Soviet industrialization. However, care must be taken to embody these general goals in a model simulation adjusted to take advantage of all the constrained possibilities defined by the specified data.

The structure of household consumption is a major concern in developing a satisfactory reference solution. If the optimizing procedure must deliver output to peasants and workers in rigidly specified proportions, it will stop when the first sectoral capacity limit is reached, perhaps leaving large amounts of unutilized capacity in other sectors and holding down both employment and income. Our consumption parameters must be adjusted to allow households to draw on such idle capacity to a limited extent so that a plausible pattern of consumption and resource use is obtained.

The structure of fixed capital stock presents a different problem. Soviet authorities clearly intended to raise the share of some sectors very markedly — especially electric power, producer goods and construction — but as sectors grew at different rates their shares would change over time and no single official set of targets for the end of 1940 was laid down. Our reference solution therefore illustrates the dimensions that total fixed capital might have reached, but in a pattern that under actual conditions would have been modified to reflect emerging opportunities or difficulties.

Finally, we must restrain the model's tendency to make no provision for a tomorrow which it does not know exists — a problem common to finite

[9] Hunter and Rutan (1980).

growth models. After several tests, a 'post-terminal' constraint which kept investment at the average of the past periods plus an exogenously specified fraction of the terminal capital stock was found to work well.

The central message of our reference solution is that the Soviet economy in 1928 contained the potential for a very substantial output expansion through 1940 under problem-free conditions, without a need for belt-tightening. Given the base period situation, no model is required to suggest such a conclusion, since the resources and growth possibilities were obviously at hand. What the model does make possible, however, are some quantitative estimates of the degree and kind of expansion that might have been possible in the absence of the negative developments that did occur.

This expansion path is summarized in table 1. The economy's gross output in period six (1939 plus 1940) could have been some 3.8 times as large as in the base period (twice 1928).[10] Deducting interindustry deliveries, the *GNP* could have risen from an index of 100 to an index of 424. Within these aggregates, consumption would have increased some 2.7-fold while investment was rising from an index of 100 to an index of 824. The stock of fixed capital at the beginning of 1941 would have been five times larger than it was at the beginning of 1929. Deliveries to final demand from the two agricultural sectors would also have risen quickly, from 15.0 billion rubles in the base period to 30.3 billion in period three, falling off slightly to 27 billion in the next two periods and 30 billion in the sixth period. (Admittedly so rapid a degree of improvement in agriculture is rather unlikely.) Over this same period the output of the service sectors would have been rising from an index of 100 to an index of 271, with the growth concentrated in the last three periods. Deliveries to final demand by the two industry sectors and the construction sector would have grown rapidly and continuously, reaching by the sixth period a level eight times higher than the base-period level. Thus would the optimistic hopes of the system's directors have been realized.

Expansion on this scale would have required a drastic shift away from consumption and toward investment. Though the absolute level of consumption would have risen from 30 to over 80 billion rubles, the share of consumption in *GNP* would have declined from 59% in the base period to a low of 28% in the fourth period and an apparently stable share of 37–38% in the last two periods. Conversely, the absolute amount of investment would have risen from 12 billion rubles to almost 100, and the share of investment in *GNP* would have increased from 23% to 55% in period four and 44% thereafter. This stress on capital formation would, of course, have raised capital stocks very substantially, to more than three times their size at the beginning of 1929. Comparison of period-to-period increments in fixed capital and in *GNP* discloses erratic changes in the incremental

[10] Twice the 1928 value must be used as a base for comparison as each period in the model is two calendar years.

Table 1

Reference solution values for gross output, *GNP*, and components, by period, absolute data in billions of rubles at base-period prices.

	Twice 1928	1st period	2nd period	3rd period	4th period	5th period	6th period	6th period index[a]
Total gross output *GNP*	106.0	122.2	149.3	182.1	258.1	331.8	405.8	383
Agricultural output	15.0	19.5	21.4	30.3	26.8	27.3	29.7	198
Industry and constructio.	16.9	26.4	39.6	51.2	89.1	107.4	135.7	803
Services	19.7	19.3	20.1	20.4	29.7	44.0	53.4	271
Total *GNP*	51.6	65.2	81.1	101.9	145.6	178.7	218.8	424
Consumption	30.6	34.4	33.2	41.0	40.6	66.7	82.4	269
Investment	11.8	20.0	33.7	41.8	79.5	79.4	97.2	824
Government services (exogenous)	5.9	7.7	10.1	12.5	14.9	17.3	19.7	334
Exports (exogenous)	1.2	1.7	2.3	3.0	3.6	4.2	4.8	400
End-of-period stock of fixed capital	65.7	74.6	102.5	122.1	192.5	248.1	327.4	498
Percent increases per period								
Total gross output		15.3	22.2	22.0	41.7	28.6	22.3	
Agricultural output		30.0	9.7	41.6	−11.6	1.9	8.8	
Industry and construction		56.2	50.0	29.3	74.0	20.5	26.4	
Services		−2.0	4.1	1.5	45.6	48.1	21.4	
Total *GNP*		26.4	24.4	25.6	42.9	22.7	22.4	
Consumption		12.4	−3.5	23.5	−1.0	64.3	23.5	
Investment		69.5	68.5	24.0	90.2	−0.1	22.4	
Percent shares in *GNP*								
Consumption	59.3	52.8	40.9	40.2	27.9	37.3	37.7	
Investment	22.9	30.7	41.6	41.0	54.6	44.4	44.4	
Absolute increments								
Fixed capital		8.9	27.9	19.6	70.4	55.6	79.3	
GNP (annualized)		6.8	8.0	10.4	21.9	16.6	20.1	
Incremental capital/output ratio		1.30	3.50	1.88	3.22	3.36	3.96	

[a]With the base period (twice 1928) taken as 100.

capital/output ratio over the first three periods, when sharp structural adjustment was taking place. The sixth period ICOR reflects the pressure of our terminal conditions, while the third and fourth period ratios between 3.2 and 3.4 indicate the steady-state properties of the economy. These lie well within the range now familiar to Third World development modelers.

Inspection of the dual valuations in this reference solution shows that the most strongly binding constraints occur in the second period (1931–1932); in particular, capital capacity in construction and electric power is severely limiting. The base period assumptions lose their tight hold on the economy after the second period, as the additions to capital stock in the third and subsequent periods are chosen by the solution algorithm rather than dictated by past history. The model simply reflects the tensions of massive structural and technological change.

Through further juggling of the weights in the objective function we could have smoothed some of the sharp fluctuations evident in this reference solution and tailored the structure of capital stock more closely to presumed Party intentions. The analytic gains would be negligible. Sharp shifts are inherent in linear programming. As long as one can assume that the set of feasible solutions is convex, a linear combination of two neighboring solutions will be feasible; gradual transitions are implicitly available, even if not strictly optimal. This particular reference solution, for example, builds 161 billion rubles worth of new-technology capital in the producer goods sector by January 1, 1941, and only 10.1 billion rubles worth for the electric power sector. We found, however, that by reversing the weights on capital stock for these two sectors we could reverse the proportions, creating 114 billion rubles worth of capital stock in electric power, and 53.4 billion in producer goods. In practice, the combined total of about 170 billion rubles could have been divided between these two sectors in almost any desired proportions within the overall set of constraints forming the model. A linear programming model tells us about the zone which bounds feasible territory; it need not be interpreted as marking out a single, unique, fine-scale 'optimal' solution.

6. A composite reconstruction of actual developments

This 'problem-free' solution embodies the hopes and expectations of Soviet authorities in the spring of 1929 before a number of major developments made expansion more difficult. The first Soviet Five Year Plan did not foresee (a) agricultural collectivization with its unfavorable impact on draft animals, livestock herds, and peasant morale, (b) the unfavorable shift in Soviet terms of trade arising from world depression, (c) the impact on labor productivity of purges and terror, or (d) a shift of industrial output and capital construction into rearmament. The problem-free solution only shows how output might have grown under ideal circumstances.

These events forced Soviet growth along a path quite different from our reference. Massive efforts raised capital formation and gross output very rapidly for the first four years, then stalled in the crisis year of 1933. This initial burst of activity also led to severe transportation bottlenecks in 1931–1934. Output and capital formation again expanded rapidly during 1934–1937, but from 1937 through 1940 further expansion was modest. Over the decade, much of the capital built was long-delayed in completion, extremely costly in real terms, and relatively unproductive when finished. When the Nazi invasion came in 1941, the USSR was barely able to withstand the blow.

The unforeseen 'coups de main' of the 1930s, taken together, ought to account for the differences between the actual path of the Soviet economy and the problem-free path spelled out in our reference solution. It should be possible to derive quantitative estimates of the relative importance of the individual events in affecting overall results. Ideally we might hope to recreate the actual record, identifying and measuring the major causal factors at work. This would not be counterfactual history — trying to estimate what did not happen — but empirical analysis of history as it did happen. It is an econometric answer to those like Edward Hallett Carr who call for a focus on the interacting complexities of events as they occurred.

For several reasons, caution is in order concerning the precision of results to be expected. Soviet statistics for the 1930s were collected under conditions that tended to produce exaggerations, and were reported in ways that distorted the record. Even if Western analysis has overcome these defects in the evidence, valuation issues during a period of marked structural transformation introduce ambiguities that make single-valued answers impossible. In addition, our ten-sector, six-period model is quite highly aggregated, and though its rigidities are reduced by a number of technical features, results generated by the model reflect its simplified design. Models with other properties would tell a different story using the same evidence. We have found, nevertheless, that extensive experimentation discloses some central tendencies that stand up under a variety of alternative assumptions and over a wide range of parametric variations. The pattern that emerges is fully in accord with the qualitative impressions that prevail among most students of the period. We assert, therefore, that our results provide useful detail that illuminates the forces at work in a very important and interesting period of structural change.

Our experiment, then, is to impose each of these major events, singly and in combination, upon the reference solution, to adjust the model's policy parameters appropriately to cushion their impact in a fashion reflecting Soviet goals, and to examine the results. Of the four factors mentioned, the effects of the purges and terror were indirect and not easily measured. However, we were able to estimate the demands of rearmament on the basis of Soviet military manpower and spending data, the deterioration in trade from Michael Dohan's work on the subject,[11] and the results of collectivization from a combination of sources.[12] The first two were clearly exogenous influences; the Soviet government had no control over the world-wide depression and little choice but to rearm. But the 'liquidation of the kulaks as a class', with its attendant effects, was solely the result of a domestic policy decision.

Summary statistics for the various solutions and comparable numbers from the historic record (when available) are presented in table 2. They are arranged to show how the record may be decomposed. Moving up from the problem-free reference solution given at the bottom of the table will take you through the effects of the world depression in trade, rearmament, these two combined, and collectivization; the top two lines show the model's composite reconstruction of events and the actual growth path of the economy. Conversely, moving down each chart steadily frees the economy from the constraints of events until the problem-free situation is reached. Note that we report capital stock from any solution including rearmament both with and without the defense component.

How closely does this reconstruction correspond to the actual historical record? In many respects we cannot be sure, since important aspects of that record remain uncertain. But some overall checks are available, and they indicate that the two match fairly well.

In the gross output panel [table 2(A)] for example, comparison of the actual estimates in line 1 with our composite reconstruction in line 2 demonstrates that our estimates have the right dimensions. The model starts out slightly below the historical level, but catches up and surpasses it.

This higher growth rate can be traced to two influences. First, the optimizing algorithm has certain advantages that planners at the time were unlikely to have had. We would expect this supra-normal efficiency to lead to a higher growth rate. But it also leads to slack capacity in some sectors in the first two periods; unaffected by the inertia which haunts real economic systems, KAPROST does not produce anything it cannot use! Second, as noted above, many of the negative impacts on the Soviet economy — the purges and terror, the transportation bottleneck, the initial overinvestment and subsequent waste — were not quantifiable for inclusion in KAPROST. Some of this is picked up in our data (the agricultural output and capital stocks, for instance), but failure to capture them fully will lead to better performance by KAPROST than real life.

[11]Dohan and Hewett (1973, pp. 5–85).
[12]See Hunter and Rutan (1980, ch. V).

Table 2

Comparing solutions (by period, in billions of rubles at base period prices).

	Period						
	1929 + 1930	1931 + 1932	1933 + 1934	1935 + 1936	1937 + 1938	1939 + 1940	
(A) Gross output							
Actual (table V-9)	127	151	169	231	281	307	
Composite (table VI-22)	115	139	154	236	307	324	
Agricultural collectivization (table VI-21)	117	140	161	244	311	320	
Depression + rearmament (table VI-13)	119	148	171	250	331	402	
Rearmament (table VI-11)	121	149	167	252	340	419	
World depression (table VI-5)	121	149	182	257	330	407	
Reference solution table IV-19	122	149	182	258	332	406	
(B) Total capital stock (start of year)	1929	1931	1933	1935	1937	1939	1941
Actual	67.3	80.5	100.9	123.5	160.2	202.6	265.9
Composite							
Excluding defense capital	67.1	71.8	93.1	125.3	164.6	239.1	229.1
Including defense capital	67.1	71.8	93.1	128.3	184.3	287.9	337.9
Agricultural collectivization	67.1	71.8	95.7	123.9	183.3	273.0	358.1

Depression + rearmament							
Excluding defense capital	65.7	74.6	98.0	125.5	171.1	244.7	262.3
Including defense capital	65.7	74.6	98.0	128.5	190.8	293.5	371.1
Rearmament							
Excluding defense capital	65.7	74.6	96.2	127.0	174.5	250.7	276.4
Including defense capital	65.7	74.6	96.2	130.0	194.2	299.5	385.2
World depression	65.7	74.6	102.4	121.8	191.4	244.9	324.2
Reference solution	65.7	74.6	102.5	122.1	192.5	248.1	327.4
(*C*) *Total consumption*							
Composite (table VI-22)	37.7	31.7	20.9	27.3	32.3	36.3	
Agricultural collectivization (table VI-21)	36.4	30.0	25.8	29.6	31.7	35.6	
Depression + rearmament (table VI-13)	36.1	35.6	32.3	31.1	37.8	47.1	
Rearmament (table VI-11)	36.2	36.2	27.5	30.8	38.4	48.4	
World depression (table VI-5)	34.7	33.4	40.4	40.6	66.6	82.6	
Reference solution (table IV-19)	34.4	33.1	41.0	40.6	66.7	82.3	
(*D*) *Unemployment (percent)*							
Composite	13.9	21.5	34.5	26.6	26.8	29.6	
Agricultural collectivization	12.4	19.6	28.6	24.3	27.9	31.3	
Depression + rearmament	9.3	13.1	14.2	4.9	7.4	0.0	
Rearmament	8.7	12.4	23.2	7.7	7.0	0.0	
World depression	8.5	12.0	0.7	0.0	0.0	0.0	
Reference solution	7.8	11.6	0.0	0.0	0.0	0.0	

A second confirmation of our composite reconstruction comes from the correspondence between its capital stock series and the most reliable available estimate of Soviet capital stocks. We show in the first line of the panel on capital stocks [table 2(B)] the index for gross capital in 1928 prices compiled by Moorsteen and Powell[13] chained to our 1928 ruble figure. The composite reconstruction tracks the Moorsteen–Powell index closely, though again our estimates are somewhat below the actual record in the early years and somewhat above it at the end.

The drastic fall in consumption displayed by our composite reconstruction, from 38 billion rubles in 1929 and 1930 to 32 billion in the next two years and only 21 billion in 1933 and 1934, cannot be checked against official or Western estimates, since no continuous estimates are available. Professor Chapman[14] long ago demonstrated conclusively, however, that the non-agricultural real wage in 1937, after substantial recovery from the most difficult years around 1933, was 17% below its 1928 level (in terms of the 1928 price structure), or 43% below its 1928 level (in terms of the 1937 price structure).

Perhaps interactions within the composite reconstruction that push its first period total consumption above the 34.4 billion rubles of the reference solution should be discounted as unrealistic; perhaps even the rise of the reference solution figure from 30.5 billion in the base period (twice its 1928 level) should be treated as unlikely. These increases reflect KAPROST's dexterity in distributing output. As capital investment is limited by capacity bottlenecks in the construction sector, extra output from agriculture, housing and consumer goods is delivered to consumers. A more sophisticated model with inventory behavior might have held back some of this for use in later periods, especially the producer goods. Alternatively, a less efficient economic system might have lost some of it through waste. In any case, the fall from 30.5 billion in the late 1920s to 20.9 billion in 1933 and 1934 represents a 31.5% shrinkage in real consumption. If the 20.9 billion is compared with the third period level of 41.0 billion attained under the problem-free conditions of the reference solution, the implication is that there was a 49% shortfall in comparison to what might have been.

Another tragic feature of the composite reconstruction is the massive volume of unemployed labor it involves. The unemployment is organically linked to the shrinkage in real consumption. Since we have maintained the same physical labor productivities throughout all the tests from the reference solution on, the successive constrictions on the economy have made more and more labor superfluous. The unemployment panel [table 2(D)] shows the results. By comparison with the reference solution, which made use of all available labor after the structural shifts of the first two periods were

[13]Moorsteen and Powell (1966, p. 322, table T-28).
[14]Chapman (1963, pp. 145–146).

completed, rearmament altered resource use in a way that generated unemployment in periods three, four, and five as well. But the impact of agricultural collectivization was far more severe, making between 24% and 31% of the total labor force unnecessary. Combining collectivization with world depression and rearmament, our composite reconstruction generates unemployment levels running from 14% in the first period to 34.5% in the third, 27% in the fourth and fifth, and 30% at the end of the decade.

By constitutional definition unemployment did not exist in the USSR: government policy kept the whole labor force on payrolls in non-agricultural establishments (together with sovkhozy), as members of kolkhozy, or in corrective labor camps. Average labor productivity per person in physical terms fell far enough below its potential to absorb the superfluous labor. Massive unemployment was thus camouflaged, by contrast with the explicitly exposed unemployment in the West during the same period.

The results displayed in table 2 reveal instructive contrasts. Inspection shows very clearly that agricultural collectivization dealt the most serious blow against the economy, far more crippling than the two external factors of rearmament and world depression. The evidence is especially vivid in terms of household consumption. Total household consumption over these twelve years comes to 298 billion rubles in the reference solution; world depression leaves the total unchanged. Rearmament lowers total consumption by 27%, to 218 billion, and the two exogenous factors in combination have the effect of restricting consumption to 220 billion. But collectivization of agriculture reduces the total by 37%, to 189 billion, and our composite reconstruction shows a twelve-year total for household consumption of 186 billion rubles.

The loss of draft animals and productive livestock did far more than reduce the flow of livestock products to the population. It forced industry to deliver tractors and other agricultural machinery more promptly than had been intended, thus making non-agricultural capital formation more difficult. It lowered labor productivity in agriculture directly, and indirectly throughout the economy as well. One sees this in table 2, where, though the total capital stock does not seem severely reduced by the imposition of collectivization, gross output in 1939 and 1940 is 25% lower in solutions including collectivization than in any of the others. The capital has been delivered to less productive uses, and the shift is obtained at the cost of severely reduced consumption.

Probably the most important consequence of collectivization, though it is not directly measurable by KAPROST, was the political tension and pressure that this 'second revolution' spread throughout Soviet society, culminating in political purges and mass terror. This is the tragic human story that underlies the laconic figures in our results.

To conclude these comparisons, we offer some overall data on *GNP* components and shares in table 3. Several striking contrasts are evident. The total *GNP* in our composite reconstruction is smaller than in the reference solution over all six periods, as is only to be expected. The shortfall is modest at first, but it is 15% in the 4th period, 11% in the 5th period, and 21% in the 6th period, as the negative developments impose their combined

Table 3

Comparison of *GNP* and its components in the composite reconstruction and in the reference solution.

	Period					
	1929+ 1930	1931+ 1932	1933+ 1934	1935+ 1936	1937+ 1938	1939+ 1940
Billions of rubles						
Consumption						
Composite reconstruction	37.7	31.7	20.9	27.3	32.3	36.3
Reference solution	34.4	33.2	41.0	40.6	66.7	82.4
Investment						
Composite reconstruction	15.3	31.1	42.9	59.7	69.9	20.7
Reference solution	20.0	33.7	41.8	79.5	79.4	97.2
Defense procurement						
Composite reconstruction	—	—	3.0	17.0	31.0	64.9
Reference solution	—	—	—	—	—	—
Government services						
Composite reconstruction	10.9	12.1	14.7	12.5	12.0	22.7
Reference solution	7.7	10.1	12.5	14.9	17.3	19.7
Exports						
Composite reconstruction	2.0	2.3	1.9	1.5	1.3	1.1
Reference solution	1.7	2.3	3.0	3.6	4.2	4.8
Gross national product						
Composite reconstruction	62.6	77.0	86.2	129.4	167.3	171.9
Reference solution	65.2	81.1	101.9	145.6	178.7	218.8
Percent shares						
Consumption						
Composite reconstruction	60.2	41.2	24.2	21.1	19.3	21.1
Reference solution	52.8	40.9	40.2	27.9	37.3	37.7
Investment						
Composite reconstruction	24.4	40.4	49.8	46.1	41.8	12.0
Reference solution	30.7	41.6	41.0	54.6	44.4	44.4
Defense procurement						
Composite reconstruction	0.0	0.0	3.5	13.1	18.5	37.8
Government services						
Composite reconstruction	10.9	12.1	14.7	12.5	12.0	22.7
Reference solution	11.8	12.5	12.3	10.2	9.7	9.0
Exports						
Composite reconstruction	3.2	3.0	2.2	1.2	0.7	0.6
Reference solution	2.6	2.8	2.9	2.5	2.3	2.2

effects. Consumption suffers markedly, as we have seen, but these sacrifices do not serve to increase investment. Collectivization and rearmament combine to hold investment down, especially in the last two years, when defenses procurement rises rapidly and fixed capital formation falls from 70 to 21 billion rubles.

The share of consumption in *GNP* declines from its starting point in both solutions, as resources are shifted into capital formation. But the belt-tightening is more severe in the composite reconstruction, where consumption accounts for only one-fifth of the *GNP* in the last three periods. This extraordinarily low share excludes public consumption, i.e., health care, education, and municipal services, which account for from 11% to 15% of the *GNP*, so it is not quite so shocking. Nevertheless it is clear that the Soviet people bore a very heavy burden during this period. Half the *GNP* was channeled into accumulation in 1933 and 1934 under the composite reconstruction, but the investment share fell off to 42% in the fifth period and dropped to 12% in the sixth, as defense procurement rose to account for more than a third of the *GNP* in 1939 and 1940.

7. Summary

The findings of our exercise in ex post planning should be recognized as rough approximations. The statistical evidence is fragile and the model is a bit clumsy. With better data and a more sophisticated model the results could be made more precise, but it is not likely that their implications would be significantly altered. This period in Soviet history was a harsh one. Great sacrifices were made, whether necessary or not, and much was accomplished, however wastefully. We hope that our technique and results will aid other countries in the search for ways to modernize at lower costs.

Appendix: The KAPROST model

In presenting the model the following conventions are used. While slightly unconventional, they greatly simplify the form of the equations.

(1) Vectors are represented by small Latin letters, matrices by capitals. Small Greek letters are used for scalar or vector parameters. The dimension of all vectors is n by 1, where n is the number of producing sectors in the economy. KAPROST has 10 sectors. Matrices are n by n.

(2) As in standard presentations, juxtaposition of a matrix and a vector represents matrix multiplication (row by column inner products). Another standard convention is that the symbol '+' indicates element by element addition. We extend this to the symbol '*' which will indicate

element by element multiplication. Scalar multiplication is represented by simple juxtaposition.

(3) Unless otherwise subscripted, the symbol '$\sum$' indicates summation of all elements of a vector.

(4) All variables are implicitly time subscripted. Where all or nearly all elements in an equation relate to the same period, t, the subscript is omitted. The subscripts '$+m$' or '$-m$' indicate leads or lags of m periods.

(5) Four superscripts are used: P–peasants, W–workers, O–old technology, N–new technology.

Glossary of symbols

Parameter matrices

- A– interindustry coefficient matrix,
- M– required import coefficient matrix; diagonal in KAPROST,
- S– delivery to inventory coefficient matrix; diagonal in KAPROST,
- R– delivery to fixed capital investment matrix.

Parameter vectors

- δ– depreciation,
- β– output–capital ratio,
- λ– output–labor ratio,
- ω– wages,
- γ– terminal investment parameter,
- θ– objective function weights,
- σ– fixed consumption structure coefficients.

Scalar parameters

- α– average propensity to consume,
- π– fixed-proportions fraction of consumption,
- κ– new capital mastery coefficient; 0.7 in KAPROST,
- T– number of simulation periods; 6 in KAPROST.

Data vectors

- x– gross output,
- z– additions to capital stock,
- k– capital stock,
- l– labor force,
- e– exports; exogenous in KAPROST,
- m– optional imports,
- g– government final demand; exogenous in KAPROST,
- f– optional deliveries to consumption.

Data scalars

c– consumption out of income,

y– income,

a– foreign trade credits,

s– total labor supply.

Equations

Objective function

$$Obj=\sum_{t=1}^{T}\theta_t^P c_t^P+\sum_{t=1}^{T}\theta_t^W c_t^W+\sum\theta^N k_{(T+1)}^N. \tag{A.1}$$

Distribution relationship

$$\underset{\text{(Inter-ind. demand)}}{A^O x^O+A^N x^N}+\underset{\text{(Deliv. to inventory)}}{S^O x^O+S^N x^N}+\underset{\text{(Deliveries to fixed capital investment)}}{R_{(+2)}^N z_{(+2)}^N+R_{(+1)}^N z_{(+1)}^N}$$

$$+\underset{\text{(Deliveries to consumption)}}{\pi^P c^P\sigma^P+\pi^W c^W\sigma^W}+f+e+g\leqq \underset{\text{(Gross output)}}{x^O+x^N}+\underset{\text{(Imports...)}}{M^O x^O+M^N x^N+m}. \tag{A.2}$$

Capital accounting

k_1^N, k_1^O, and z_2^N are exogenous,

$$k^N=(1-\delta^N)*k_{(-1)}^N+z^N, \tag{A.3}$$

$$k^O=(1-\delta^O)*k_{(-1)}^O.$$

Productivity constraint

$$x^O\leqq\beta^O*k^O,$$

$$x^N\leqq\beta^N*(\kappa z^N+(1-\delta^N)*k_{(-1)}^N), \tag{A.4}$$

$$x^O\leqq\lambda^O*l^O,$$

$$x^N\leqq\lambda^N*l^N.$$

Labor supply constraint

$$\sum l^O+\sum l^N\leqq s. \tag{A.5}$$

Income and consumption

$$y^P = \sum_{i=1}^{2} \omega_i (l_i^O + l_i^N),^{15}$$

$$y^W = \sum_{i=3}^{10} \omega_i (l_i^O + l_i^N),^{15}$$

$$c^P \geqq \alpha^P y^P,$$

$$c^W \geqq \alpha^W y^W, \tag{A.6}$$

$$c^P + c^W = \pi^P c^P + \pi^W c^W + \sum f.$$

Balance of payments constraint

$$\sum (M^O x^O + M^N x^N + m) \leqq a + \sum e. \tag{A.7}$$

Terminal investment constraint

$$z^N_{(T+2)} \geqq \frac{1}{T} \sum_{t=2}^{T+1} z_t^N + \gamma^N * k_T^N. \tag{A.8}$$

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[15]Here the subscripts refer to sectors of the economy. All variables also have an implicit time subscript.

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