THE HOPKINS-KENNEDY OPTIMAL CONTROL MODEL OF THE SOVIET ECONOMY

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The purpose of today's presentation will be to discuss the Hopkins-Kennedy optimal control model of the Soviet economy and some of the results which have been produced by the model for various scenarios. As indicated in Fig. 1, I shall place particular emphasis on scenarios concerning weather, foreign trade, energy, alternative views of the basic nature of the Soviet economy, and technology.

In order to give an intuitive feel to those here today, who are not familiar with optimal control models on how the Hopkins-Kennedy model operates, I shall first discuss a very simple degenerate optimal control model. This is depicted in Fig. 2. There is one time period and two types of output, guns and butter, which can be produced from a given set of inputs. The cross hatched area is the set of all technically feasible outputs. This is bounded by the production possibility frontier and the coordinate axes. Diagrams such as this are commonly found in Introductory Economic textbooks. Most of the results of the Hopkins-Kennedy model, which I shall present today, are in terms of trade-off curves between consumption and defense for projections initiated in 1980 and run to 1990. These tradeoff curves are analogous to the production possibility frontier in Fig. 2. They will have the rate of growth of consumption instead of butter on the X axis and the rate of growth of defense spending instead of guns on the Y axis. Loosely speaking, both the production possibility frontier and the

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[1]Given at a conference on Soviet economic modeling sponsored by the Rand Corporation in Washington, D.C., October 11-12, 1984. The material for this presentation was mainly drawn from two reports sponsored by the Director of Net Assessment, Office of the Secretary of Defense. These may be consulted for additional and more detailed information (Hopkins, M. M., and M. P. Kennedy, *Comparisons and Implications of Alternative Views of the Soviet Economy*, The Rand Corporation, R-3075-NA, March 1984 and Hopkins, M. M., and M. P. Kennedy, with the assistance of M. F. Lawrence, *The Tradeoff Between Consumption and Military Expenditures for the Soviet Union During the 1980s*, The Rand Corporation, R-2927-NA, November 1982.)

PURPOSE

1. Discuss model and a few of the results
2. Emphasis on
   - A. Weather
   - B. Foreign trade
   - C. Energy
   - D. Alternative views
   - E. Technology

Fig. 1

A SIMPLE OPTIMAL CONTROL MODEL

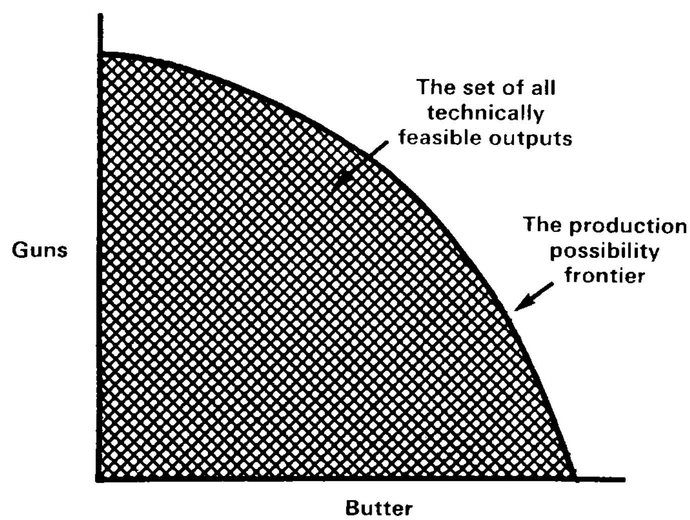

Fig. 2

tradeoff curves produced by the model are such that the production of one type of output cannot be increased without reducing the production of another. Of course, the Hopkins-Kennedy model is much more complicated than that shown in Fig. 2.

A gross outline of the Hopkins-Kennedy model is given in Fig. 3. It has 21 sectors. There are three factors, labor and two types of capital. The production function for each sector is translog. Production in one sector consumes some of what was produced in the other sectors in accordance with an input-output table. The input-output table also ensures that the net and gross outputs of the economy are consistent.

THE MODEL

1. 21 sectors — 3 factors (labor and 2 types of capital) — translog production functions
2. First set of decisions in year 1 — labor allocation
3. Second set of decisions in year 1 — investment goods allocation
4. Repeat for additional years
5. Use optimal control to find the tradeoff curve

Fig. 3

In the model, the first set of decisions that decisionmakers make in year 1 is how to allocate the available supply of labor across all of the sectors. Associated with each sector is a fixed initial amount of the two types of capital. Next, production occurs. Some of the resulting output is in the form of investment goods. The second set of decisions which decisionmakers make in year 1 is how to allocate investment goods across different sectors. After taking into account depreciation, this allocation results in a new level of each of the two types of capital for each sector. We repeat this process for year 2 and subsequent years for the time period in question.

The resulting solution for the economy is analogous to a point in the cross hatched area of Fig. 2. It is one of many technically feasible sets of intertemporal outputs. The optimal control procedure in the model is used to find from the set of all possible such solutions of the economy, a subset which is analogous to the production possibility frontier of Fig. 2. This is what we use for our tradeoff curve.

As we all know, the Soviet economy is not optimally run. The model takes this into account by assuming that various forms of inefficiency which are apparent from the data for the initial year of a projection continue into the later years of the projection. For example, the production functions which are calculated from data for the initial year represent inefficient production processes by Western standards. These production processes are assumed, loosely speaking, to remain equally inefficient for the duration of the projection, save to the extent that there is growth in total factor productivity for the economy as a whole. I shall discuss the assumptions in the model concerning the rate of total factor productivity growth later.

The names of the 21 sectors of the model are shown in Fig. 4. The first 18 of these are the net material product sectors. They were taken from Treml data. To these we added two defense sectors, procurement and other defense. The last sector labeled "other" contains everything in the economy which is not covered elsewhere. This is mainly services.

THE SECTORS

1. Ferrous metallurgy
2. Non-ferrous metallurgy
3. MBMW (Machine Building Metal Working)
4. Forest products
5. Soft goods
6. Processed foods
7. Construction materials
8. Coal and peat
9. Oil
10. Gas
11. Electric power
12. Chemicals
13. Paper and pulp
14. Construction
15. Agriculture
16. Transportation & communication
17. Trade and distribution
18. Industry nec and other
19. Procurement
20. Other defense
21. Other

Fig. 4

The traoeoff curve for our base case 1980-1990 projection is shown in Fig. 5. This and all of the other results which I am presenting today were calculated two or more years ago. More accurate predictions could obviously be obtained, if the analysis was redone using current data. However, the results that we currently have are sufficient for today's discussion. On the Y axis of Fig. 5, we have the average annual rate of growth of defense spending for the decade. On the X axis, we have the average annual rate of growth of consumption. To calculate a point on the tradeoff curve, we assumed a specific average annual rate of growth of defense spending and then, using the model, we maximized the discounted sum of consumption over the period. This sum was then converted to an average annual rate of growth of consumption. We

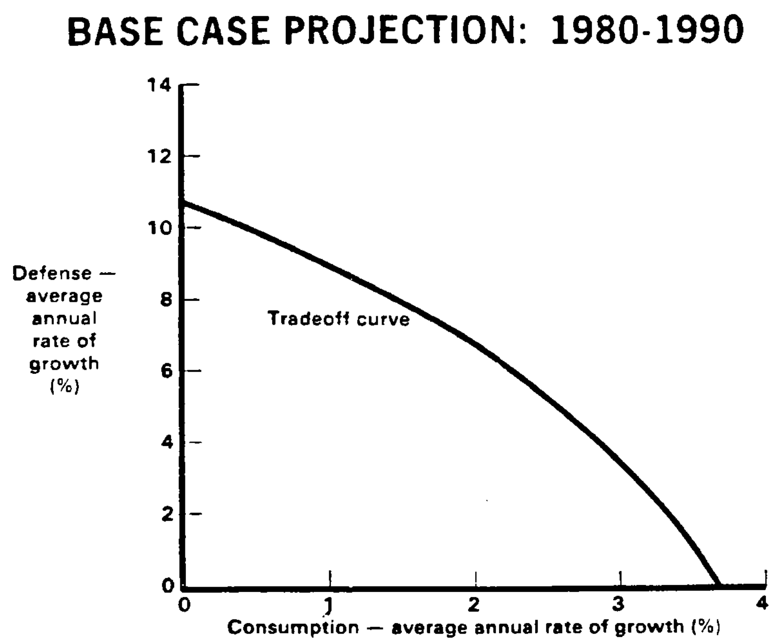

Fig. 5

employed for the discount rate the same rate which we calculated by using the model as giving the best fit to the data for the 1960-1975 period.

One particularly useful method for testing a model is to use it to predict past history. In Fig. 6 the results for the projection for 1960 to 1975 are shown. Note that the point representing the actual experience for the period lies nicely on the tradeoff curve.

Another procedure for testing the model against history is to estimate the size of GNP for each year of a projection and compare this with what actually occurred. Fig. 7 shows such an estimate as a dashed line, while the actual values are shown as a solid line. To estimate GNP for a given year, such as 1970, the model was run from the base year

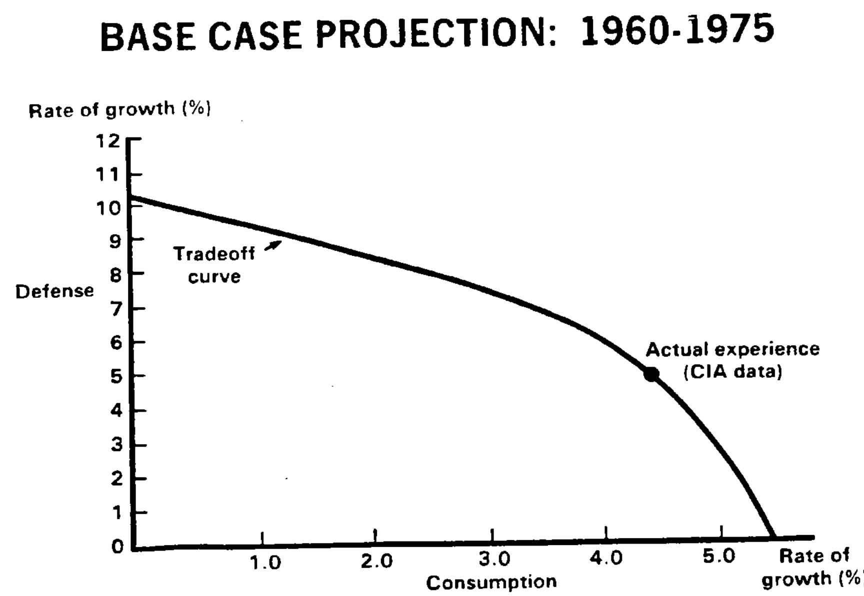
BASE CASE PROJECTION: 1960-1975
Rate of growth (%)
12
11
10
9
8
7
6
5
4
3
2
1
0
Defense
Tradeoff curve
Actual experience (CIA data)
1.0
2.0
3.0
4.0
5.0
Consumption
Rate of growth (%)

Fig. 6

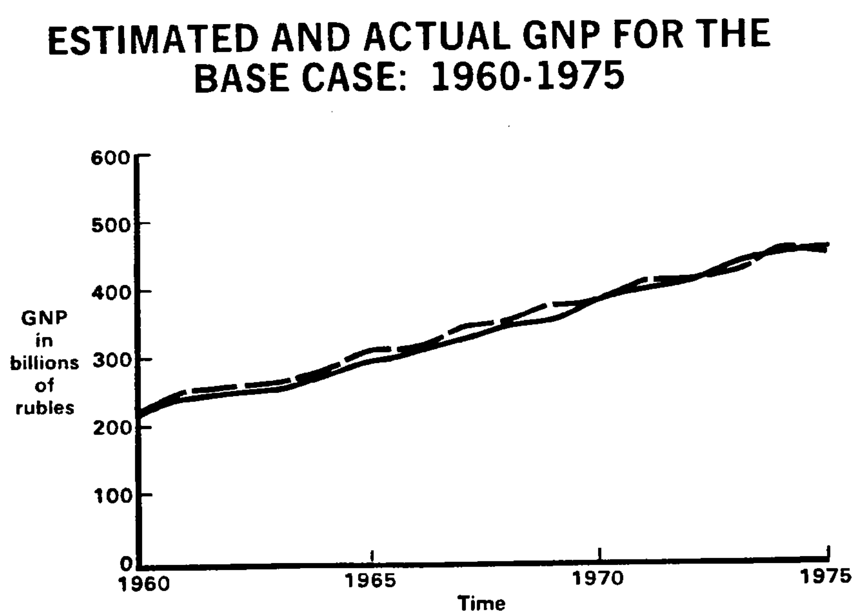
ESTIMATED AND ACTUAL GNP FOR THE BASE CASE: 1960-1975
600
500
400
300
200
100
0
GNP in billions of rubles
1960
1965
1970
1975
Time

Fig. 7

of 1960 to the given year. A curve such as in Fig. 6 was thus obtained. Then the actual average annual rate of growth of defense spending for the period 1960 to the year in question was used to calculate from the tradeoff curve an average annual rate of growth of consumption. Finally, the corresponding levels of defense spending and consumption for the year in question were summed with the level of investment which the model endogenous predicts for that year to obtain our estimate of GNP. As a rule, this should lead to projections which decrease in accuracy as we get farther and farther away from the base year, although this is not particularly the case for the example given in Fig. 7. The power of the model is indicated by the generally small differences between estimated and actual GNP in Fig. 7.

Let us now turn our attention to a number of special features of the model. Fig. 8 indicates how the model handles weather. The model has an adjustment factor in the agricultural production function which changes the level of agricultural output for a given set of inputs depending on the weather. The model assumes that decisionmakers at the beginning of a projection would assume in the absence of information to the contrary that weather would be normal for every year of the projection. Optimization is then carried out under this assumption and generates the inputs for the agricultural sector in year 1. In scenarios where weather is not normal in every year, the model then assumes that at the end of year 1 decisionmakers discover the extent to which the actual weather has departed from normal. At this point, it is assumed that it is too late to alter the inputs for the agricultural sector for year 1, but that decisionmakers can and do reoptimize for year 2 and later years taking into account the weather at year 1, its effect on agricultural output, and an assumption that in year 2 and later years the weather will be normal. This procedure is then reiterated for each successive year until the end of the period.

Fig. 9 compares the base case of Fig. 5, which assumes normal weather for all years of the decade for which we did not have weather data at the time the projection was run, with a poor weather scenario. The later scenario assumes that weather in the 1980s will be similar to the particularly poor weather period of the late 1970s. The difference

WEATHER

1. Weather adjustment factor applied to the agricultural sector
2. First, optimize normally
3. Assume inputs to agriculture are at this level for year 1
4. Adjust for year 1 weather
5. Reoptimize later periods
6. Reiterate

Fig. 8

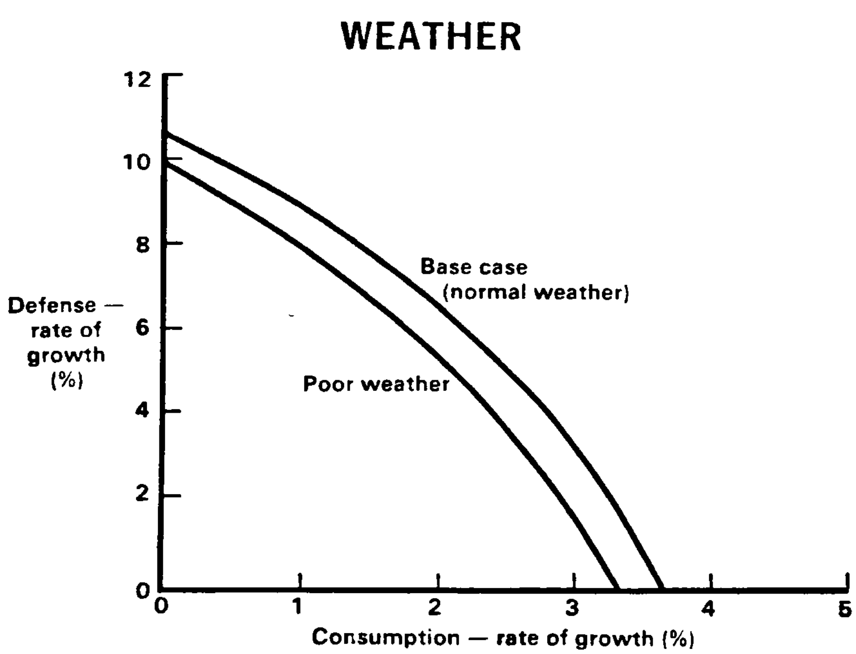

Fig. 9

between the curves indicates that weather has a small to moderate impact on the Soviet economy as compared to most of the issues which we have examined in our various studies.

Fig. 10 indicates how the model deals with foreign trade. We have three endogenous variables: oil exports from the Soviet Union to the industrialized West; agricultural imports from the industrialized West to the Soviet Union; and MBMW imports from the industrial West to the Soviet Union. The remainder of trade is handled exogenously. Also, there is an exogenously specified credit constraint defined as the maximum amount for each year of a projection that the Soviets may borrow above the amount they repay on past loans. Finally, the efficiency of foreign produced capital is assumed to be higher than domestic produced

FOREIGN TRADE

1. ENDOG:
   - A. Oil exports to
   - B. Agricultural imports from
   - C. MBMW imports from

     The industrialized West
2. EXOG:
   - A. Remainder of trade
   - B. Credit constraint
3. Efficiency of foreign capital set higher than domestic capital

Fig. 10

capital. In accordance with the results of a literature search on this subject we took the relative efficiency to be 1.5 for our base case.

Let us first consider the impact on the tradeoff curve of differing assumptions concerning credit. The base case assumes that the amount of credit (amount borrowed - amount paid back) that the Soviets will utilize is $2.2 billion per year for the remainder of the 1980s. This is the average amount that the Soviets obtained in the 1973-1981 period. We have defined a low credit scenario, where the Soviets receive zero credit (just enough new funds to turn over the existing debt) for each year for the remainder of the decade, and a high credit scenario, where the Soviets receive twice as much as in the base case. The tradeoff curves for the low and high scenarios are compared in Fig. 11.

The tradeoff curve for the low composite credit scenario is also shown in Fig. 11. This scenario was designed to show a case where the Soviets are actually paying out more than they are taking in. It assumes a loss of $3.2 billion per year. The $3.2 billion figure was arrived at by assuming that the Soviets receive zero credit; that they will take over part of the debt obligations of their Eastern European satellites (this seemed more likely when we did this analysis than it does now); and that the Soviets will increase foreign aid to some of their client states such as Afghanistan.

The comparison of the three tradeoff curves that I have discussed in Fig. 11, indicates that credit and related issues have a relatively small impact on the base case projection as compared to some of the other issues that we have been concerned with in our studies.

Next, consider the impact on the base case of differing values of the ratio of the efficiency of foreign as compared to domestic produced capital. Estimates in the literature of this ratio vary from 1 to 10 (our base case being 1.5). The effect of this wide range on our tradeoff curve is shown in Fig. 12.

Note that the gap between the two curves in Fig. 12 increases as we move from low to high rates of defense growth. This occurs because, at low rates of defense growth, the fraction of imports that are agricultural goods as opposed to MBMW in the form of capital goods is relatively large. Thus, the impact at higher relative capital

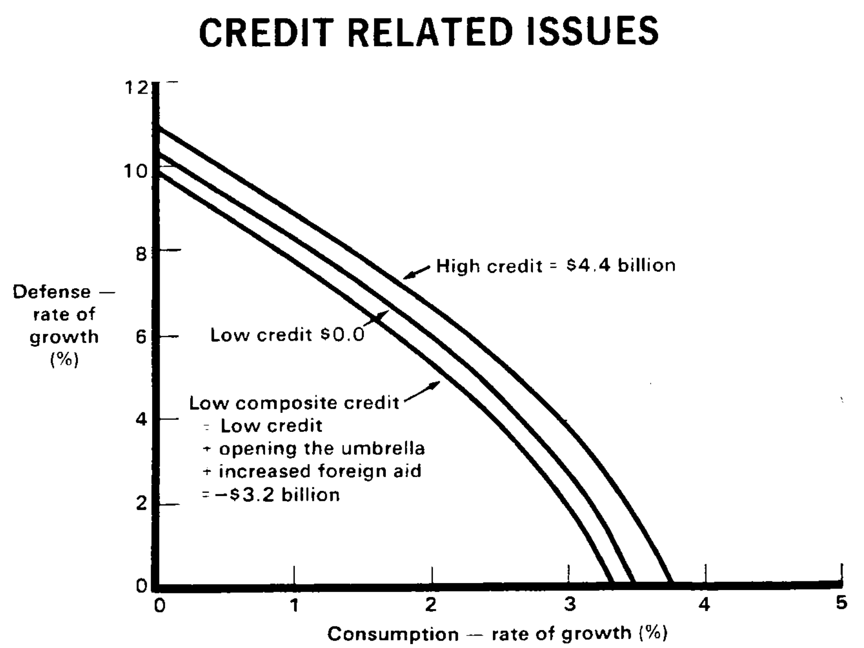
CREDIT RELATED ISSUES
High credit = $4.4 billion
Low credit $0.0
Low composite credit
= Low credit
+ opening the umbrella
+ increased foreign aid
= −$3.2 billion
Defense — rate of growth (%)
Consumption — rate of growth (%)
0
2
4
6
8
10
12
1
3
5

Fig. 11

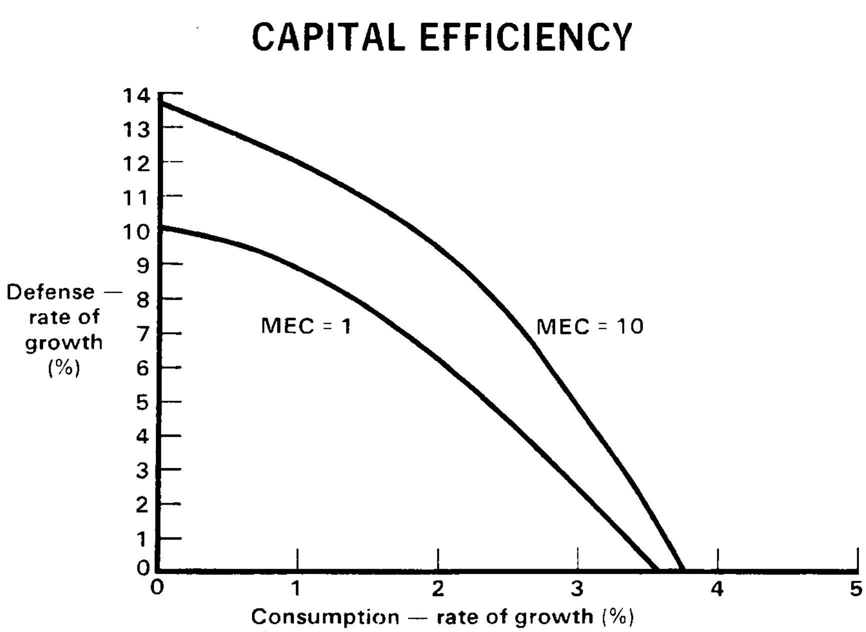
CAPITAL EFFICIENCY
MEC = 1
MEC = 10
Defense — rate of growth (%)
Consumption — rate of growth (%)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14

Fig. 12

efficiency on the curve is small. The opposite occurs when the growth rate of defense is high and capital imports are relatively large.

Fig. 13 explains how we dealt with oil in the model. Similar procedures were used for the other major sources of energy, coal and natural gas. The model assures that resource exhaustion is occurring and incorporates this effect as if it were a negative 2% rate of technological change specially applicable to the oil sector. The model also takes into consideration the fact that the price of oil can change leading to substitution effects with regards to oil in both production and consumption. Lacking useful data on the Soviet Union, we assumed that the long run elasticities of substitution for oil in production was the same as the .6% figure which has been calculated for the world as a

ENERGY

1. **Costs rise due to oil depletion as a function of time via a parameter which makes the oil sector increasingly inefficient at a rate of 2%.**

2. **The long run elasticity of substitution between oil and other inputs is .6.**

3. **The long run elasticity of substitution between oil and other goods for final consumption is .6.**

Fig. 13

whole. Recall that intermediate goods are utilized in the production of various goods in the model. Our assumption allows for the substitution of other intermediate goods fór oil, if the relative price of oil rises. Similarly, the .6% long run oil elasticity of substitution in consumption for the world as a whole was assumed to hold for the Soviet Union. Thus, if the price of oil rises in the Soviet Union, the model allows other final consumption goods to be substituted.

Fig. 14 investigates the effects of alternative assumptions concerning what the future world price of oil will be. At the time that we last did an oil price analysis, it was generally assumed that the price of oil would continue to rise in real terms. The base case assumes that this will occur at 3 percent per year. The scenario

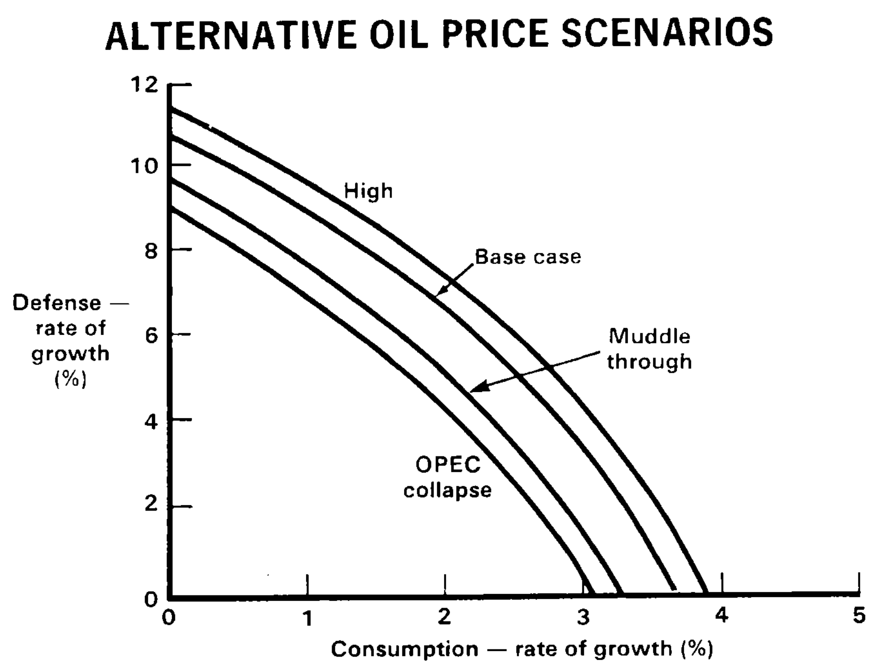

Fig. 14

labeled "High" in Fig. 14 assumes a faster rate of 5 percent per year, a rate which was chosen after a literature survey. After the research for our last project was thought to be completed, but before the final draft of the report, there was a crisis in OPEC and some talk that the organization might collapse. Consequently, we analyzed two additional oil price scenarios, "Muddle through" and "OPEC collapse." The tradeoff curves for these are shown in Fig. 14. The first of these scenarios assumed that the price of oil would be lowered by OPEC to $29 per barrel for the remainder of the decade. Shortly after the report was completed OPEC did drop its price to $29 where it has remained ever since. In the second scenario, it is assumed that OPEC is dissolved and that the price falls to $16 per barrel for the remainder of the decade.

It is of interest to compare our base case with two dramatically different views of the nature of the Soviet economy. Our base case depicts what may loosely be called the "CIA world." The base case is consistent with what the CIA believes to have occurred in the past with regards to GNP, capital, etc. It is also similar to what the CIA sees as the likely future although there are differences, the most important of which is a different assumption on what the rate of total factor productivity growth will be. The "CIA world" is the establishment position among Soviet experts. Within the "CIA world" just as within establishment positions on most issues, there is some disagreement, but this is small compared to the differences between the "CIA world" and the other two views of the Soviet economy that I shall discuss. We have labeled these to be the "Birman-like" and "Rosefielde-Lee worlds." The tradeoff curves for comparable base cases for all these worlds are shown in Fig. 15.

The "Birman-like world" is based loosely on the views at the time at which we conducted this analysis of Igor Birman, a Soviet emigre economist. We call it the "Birman-like world" instead of the "Birman world" because his views were not well defined on many of the issues relevant to building a model of his "world." The "Birman-like world" has a 1980 GNP which is 60% of the value of the 1980 GNP of the "CIA world" and a defense share which is 50% lower.

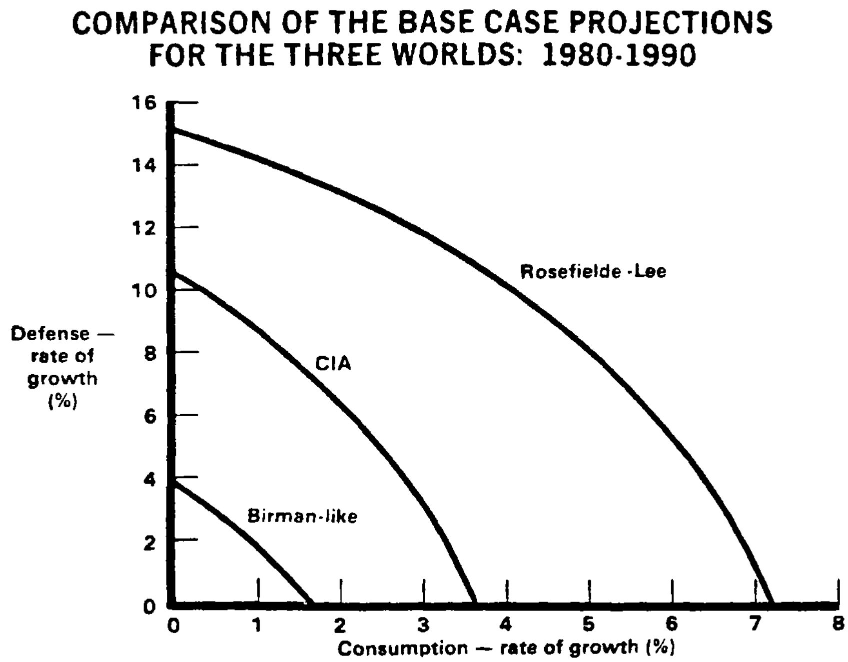

Fig. 15

The "Rosefielde-Lee world" is derived from the similar but not identical views of Steven Rosefielde and William Lee. It has a 1980 GNP which is 30% larger than that of the CIA and a defense share which is 25% lower.

The "Birman-like world" not only has a smaller GNP and a larger defense share than the "CIA world"; it also has slower technological growth. The "Rosefielde-Lee world" differs not only because of its larger-than-"CIA-world" GNP but also because of its larger-than-"CIA - world" rate of technological growth. In some sense, the "Birman-like world" is less dynamic than the "CIA world," while the "Rosefielde-Lee world" is the opposite.

The tremendous difference between the three worlds is evident in Fig. 15. The difference between the tradeoff curves is larger than for any other issue that we examined.

One of the advantages of optimal control models is that they are particularly good at exploring the implications of dramatically different scenarios. Essentially, the same model was used to examine all three of the worlds and within each world to look at such issues as the impact of differing assumptions concerning foreign trade, energy, etc. This is possible because, loosely speaking, optimal control models are less dependent on the extrapolation of past trends for their results than are other techniques.

The last topic that I shall discuss today is the impact of differing assumptions concerning the rate of total factor productivity growth in the CIA world on our base case tradeoff curve. Fig. 16 presents three scenarios. The base case assumes that the average annual total factor productivity growth rate for the 1980s will be .1% per year which is about the same as it was during the 1970s. The upper curve assumes that the rate will be .94% which is what is implied for the first half of the decade by the eleventh 5-year plan. Given past Soviet history in meeting the total factor productivity goals of their 5-year plans, it is safe to use the .94% figure as something of an upper bound. The choice of a figure which could be taken as something of a lower bound was more arbitrary. During the latter part of the 1970s, total factor productivity growth averaged -.5% per year. We assumed that matters could deteriorate somewhat further and took for this rate -1.0%.

The difference between the scenarios indicated in Fig. 16 is not as large as the difference between the "Rosefielde-Lee" and "Birman-like worlds," but it is larger than for any other issue that we examined within the context of the "CIA world".

In closing, I would like to emphasize three points. We have found that optimal control is an excellent tool for analyzing the Soviet economy. Which of the three "worlds" is correct, has the largest impact of any of the issues that we have studied. Finally, within a particular "world," issues concerning the rate of total factor productivity growth

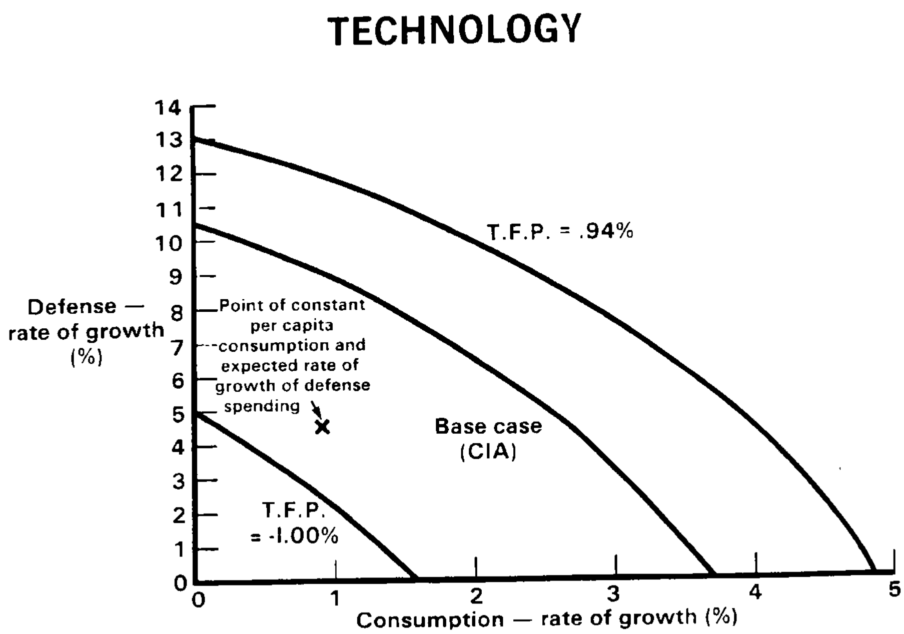

Fig. 16

are the most important. Indeed, it is our belief that a substantially increased emphasis should be placed on research in this area.

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