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To recipients of DI Paper SOV 88-10054, August 1988, *Modeling Soviet Agriculture: Isolating the Effects of Weather*: This unclassified report documents the development and use of a model to examine past trends in agricultural productivity, measures the relative contribution of labor and capital to farm output, and assesses Soviet prospects for meeting the goals of the 12th Five-Year Plan. [redacted] 25X1

[redacted] 25X1

[redacted] The agriculture model is currently used in CIA's macroeconomic model of the Soviet Union, [redacted] 25X1 25X1

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Directorate of
Intelligence

Modeling Soviet Agriculture: Isolating the Effects of Weather

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SOV 88-10054
August 1988

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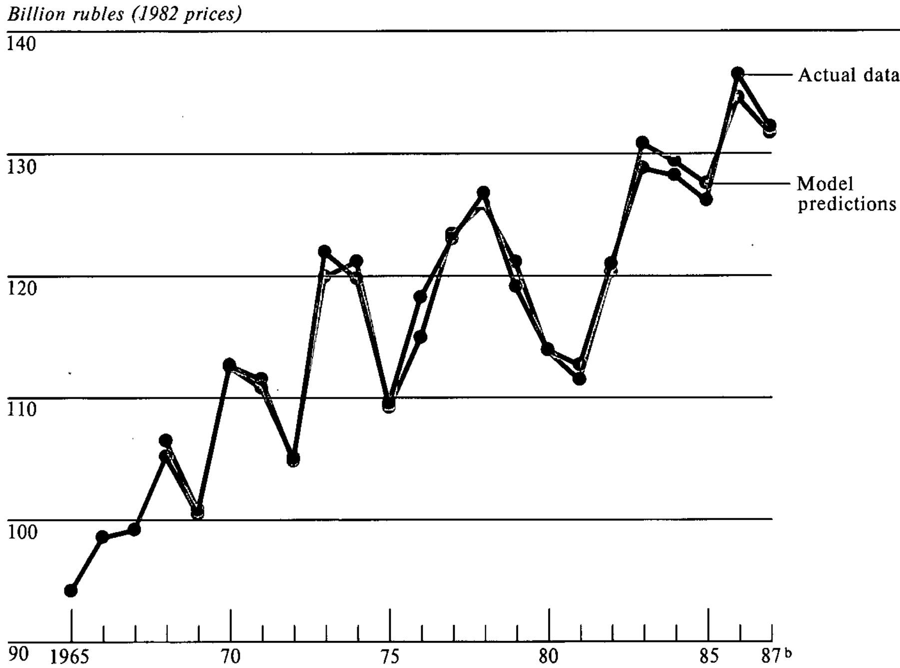
Figure 1
Observed Farm Output and the Model's Prediction, 1965-87[a]



[a] Net of feed, seed, and waste.
[b] Preliminary

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Modeling Soviet Agriculture: Isolating the Effects of Weather

Summary

Information available as of 1 June 1988 was used in this report.

General Secretary Gorbachev needs to improve food supplies dramatically to bolster popular support for the economic restructuring program. Moscow's campaign to "intensify" agriculture, particularly grain production, has resulted in recent gains. But agriculture still faces serious problems, and, unless strong measures are taken to stimulate productivity on the farm, Moscow will become increasingly unable to meet the demand for more and better food supplies without resorting to substantial hard currency imports.

Gorbachev has been seeking ways to overcome the gross inefficiencies of the agroindustrial sector. Agricultural reforms since he came to power include the creation of the superministry Gosagroprom, endorsement of collective contracts for farmworkers, enforcement of stable procurement plans, and promotion of the right of farms to directly market a portion of planned fruit and vegetable procurement. Gorbachev's call in 1987 for a special Central Committee plenum to tackle comprehensive agricultural reform suggests that more policy initiatives in agriculture are on the way. To evaluate the effects of such initiatives, it is first necessary to isolate the effects of weather, which often mask the influences of other variables on agricultural performance.

Isolating Weather Factors

A mathematical model was developed to separate the effects of weather from the effects of other factors. In developing the model, it became clear that weather factors alone were not sufficient to explain agriculture's dismal showing during the 1979-82 period. When capital, labor, and productivity changes were included in the model, the results tracked closely actual fluctuations in output (see figure 1).

The rate at which weather-adjusted output is increasing has important implications for Gorbachev's agriculture policy. Until 1979 weather-adjusted output increased steadily, reflecting relatively stable growth of inputs, steady but slow technological progress, and the absence of sharp swings in government policy (see figure 2). Weather-adjusted output dropped precipitously in 1979 and continued to decline in 1980 and 1981. During this time, growth of deliveries to agriculture slowed as overall

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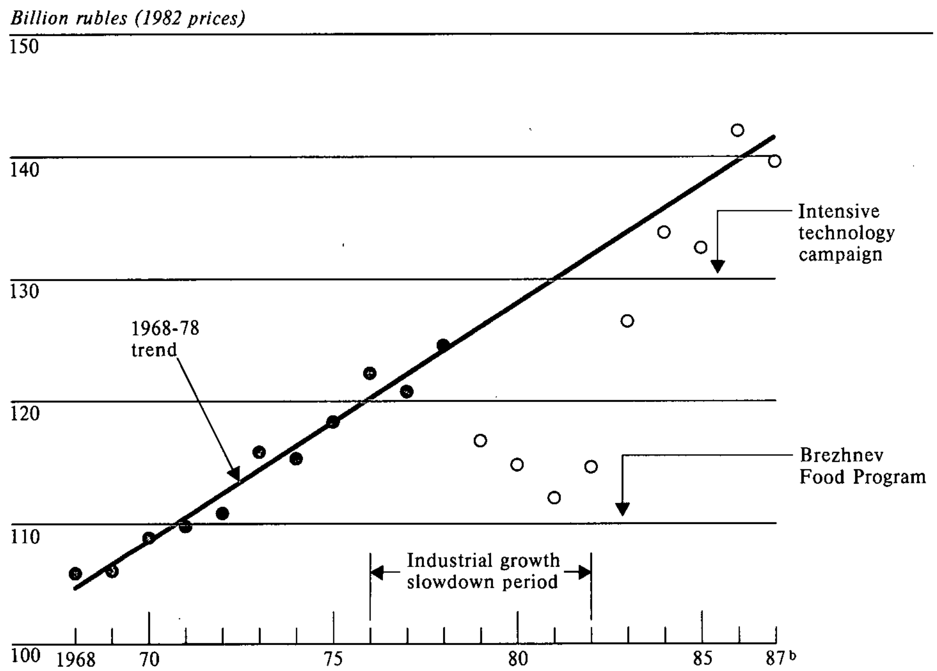
Figure 2
Farm Output After Adjusting for Weather, 1968-87[a]



[a] Net of feed, seed, and waste.
[b] Preliminary

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industrial growth slowed, and transportation organizations were increasingly unable to keep pace with the growing requirements. In addition, government policies specific to agriculture were flawed:

- Investment resources going to agriculture were wastefully allocated and inefficiently utilized. Soviet authors have complained about losses of agricultural products because construction of storage facilities and rural roads was neglected.
- Agricultural machinery downtime increased, efficiency in the use of inputs—especially machinery, equipment, and fertilizers—declined, and growth in livestock herds outstripped growth in feed availability.

In 1983, however, there was a remarkable recovery, reflecting improvements in efficiency stemming from the Brezhnev Food Program implemented the previous year. Since Brezhnev's death in late 1982, Gorbachev has used his influence in the leadership to reshape the program to reflect more closely his own views and priorities. In addition to measures targeted at increasing worker productivity, Gorbachev has given the "intensive technology" program a high priority. Intensive technology, as defined by the USSR, includes many practices routinely performed in the West—use of high-yield varieties, planting after fallow where possible, implementing efficient field operation schedules, and extensive use of agrochemicals. By 1984 and 1985 weather-adjusted agricultural output had nearly returned to the pre-1979 trend, and performance was clearly back on trend in 1986 and 1987.

Returns to Capital and Labor

The model results also show that the return to capital is lower in agriculture than in any other producing sector of the economy except fuels, and thus underscores the burden imposed on the rest of the economy by agriculture's large share of investment resources. The capital elasticity was estimated to be 0.17, indicating that a 1-percent increase in the capital stock results in only a 0.17-percent increase in output. The return to labor in agriculture, on the other hand, is estimated by the model to be over four times higher than the return to capital.

These results demonstrate why the Soviets are concerned about productivity in agriculture. The structure of the model implies that Moscow has three potential policy options for increasing farm production: increase the capital stock by accelerating growth in capital investment; increase the number of workers and/or hours worked per worker, including increases in the number of part-time workers; and increase productivity. The low return to capital relative to alternative investments in other sectors of the economy suggests that increasing capital investment in agriculture is not in the best interest of the overall economy. Increasing the labor input is not feasible because the size of the labor force in agriculture is declining as a result of natural demographic trends, which Moscow cannot change, and the leadership is opposed to increasing part-time employment in agriculture at the expense of production in other sectors of the economy. The only remaining policy option is to increase the *productivity* of the labor and capital inputs.

This can be accomplished if Moscow continues to push for programs and policies designed to increase worker efficiency. Before significant progress is possible, longstanding impediments to productivity growth must be overcome, including:

- A weak link between the size, quality, and costs of harvests and the financial rewards for farm workers and managers.
- The low quality and inappropriate assortment of farm machinery.
- Rural living conditions that are still too stark to encourage younger, skilled workers to stay on the farm.
- A rural education system that is inadequate for teaching modern agricultural practices.

Outlook

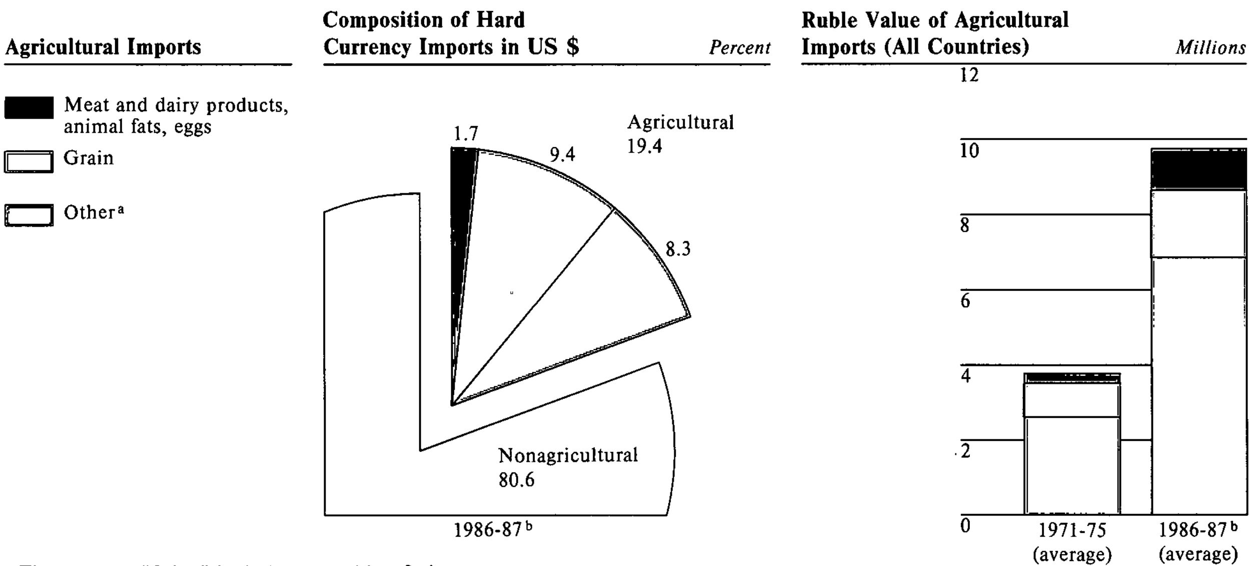
The model was used to evaluate prospects for meeting the 1986-90 Five-Year Plan goal for agricultural output. Farm output for 1988, 1989, and 1990 was projected after making assumptions about capital and labor growth and simulating alternative outcomes for weather and government policy. Model simulations indicate that the Soviets would be able to meet their plan only if the following three conditions prevail:

- At least "average" weather for 1988-90.
- Continued growth of inputs from other sectors at a rate equal to that of recent years (4 percent in 1986), together with timely deliveries.
- Productivity gains equivalent at least to a 1-percentage-point increase above that required to offset employment losses.

If any of these conditions are not met, the goal will be out of reach. Even with good weather, substantial gains in productivity are required to meet the five-year plan. Regardless of how successful ongoing and new agricultural policies are, however, bad weather—especially if it occurs in two consecutive years—could spawn an agricultural failure severe enough to exacerbate current consumer dissatisfaction with food supplies and threaten the success of Gorbachev's reform effort. Although the probability that bad weather will occur in two consecutive years is low, the impact on Soviet domestic policy—and foreign trade—would be high.

Contents

Figure 3
Soviet Dependency on Other Countries for Farm Products



[a] The category "Other" includes vegetables, fruits, sugars, natural fibers, animal byproducts, tobacco, spices, coffee, tea, wine, and fruit beverages.

[b] Preliminary.

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Modeling Soviet Agriculture: Isolating the Effects of Weather

Gorbachev Needs a Success in Agriculture

Agriculture will play an important role in determining how successful General Secretary Gorbachev will be in revitalizing the Soviet economy. The next few years will be difficult ones for the economy as a whole as Soviet managers and workers attempt to cope with the numerous and wide-ranging elements of the reform program. Gorbachev has already encountered serious opposition to the pace of reform, and additional resistance is expected as implementation spreads. The General Secretary, who built his career in part as an agricultural expert, needs a success in agriculture; failure to improve the food supply will not only be damaging to him politically, but could also undermine popular support for the economic restructuring program.

Increasing *productivity* in agriculture—increasing output per unit of inputs—is as important as increasing the food supply because of the high resource cost of farm production in the Soviet Union. The food production sector—agroindustrial complex in Soviet parlance—is immense, claiming roughly one-third of total annual investment (including related housing and services) and employing nearly 30 percent of the labor force.[1] Direct farm production activity alone claims about 20 percent of annual investment and 20 percent of the labor force compared with less than 5 percent each in the United States. Despite the huge investment in agriculture, however, the Soviet Union must still import large quantities of agricultural products, particularly grain (see figure 3). Productivity increases in agriculture would enable Gorbachev to divert resources (labor and capital investment) from agriculture to the industrial modernization drive and to reduce outlays of scarce hard currency for farm products.

[1] The food production sector includes not only farms but also several branches of industry supplying farms with materials, such as tractors and other farm machinery, repair services, and agrochemicals, and branches of industry that process food products.

A Model of Soviet Agriculture [2]

The impact of government policies to raise agricultural productivity is often hard to detect because weather effects are so overwhelming that they obfuscate the influences of policy changes and changes in quality and quantity of inputs. To properly evaluate any new program that Gorbachev may implement, it is first necessary to isolate the effects of each of the main factors influencing farm production.

Factors Influencing Performance

Any macroeconomic model of the agricultural sector must account for six broad categories of factors that influence production: capital stock, labor, material inputs (such as manufactured fertilizers), weather, technology, and government policy. In the Soviet case, some of these factors are completely controlled by Moscow, whereas others are partially controlled or completely outside the government's influence. For example, Moscow controls the flow of capital investment and material inputs into agriculture through the planning process. The supply of labor, on the other hand, is partly determined by demographic trends, over which Moscow has no direct control. Moscow can, however, influence the supply and "quality" of the agricultural work force to some extent through government policies such as those directed at relocating labor and at providing incentives to attract skilled workers to agriculture. Weather, of course, is completely outside Moscow's control.

Capital Stock and Investment. Since 1970 the stock of agricultural machinery, equipment, and nonresidential structures has more than tripled. Fixed productive capital in agriculture at the beginning of 1987

[2] The model deals strictly with agricultural output and does not address other important components of the agroindustrial complex, such as the food processing industry and the supply of industrial products to farms.

Figure 4
Growth of Capital Stock in Soviet Agriculture, 1965-86

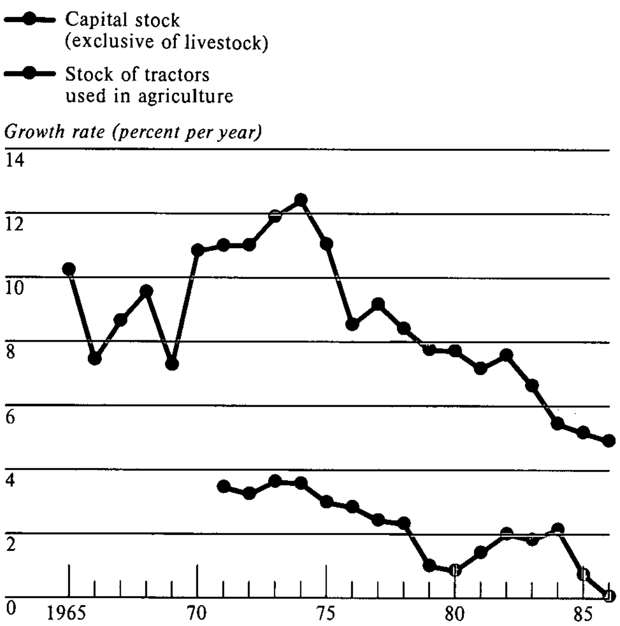

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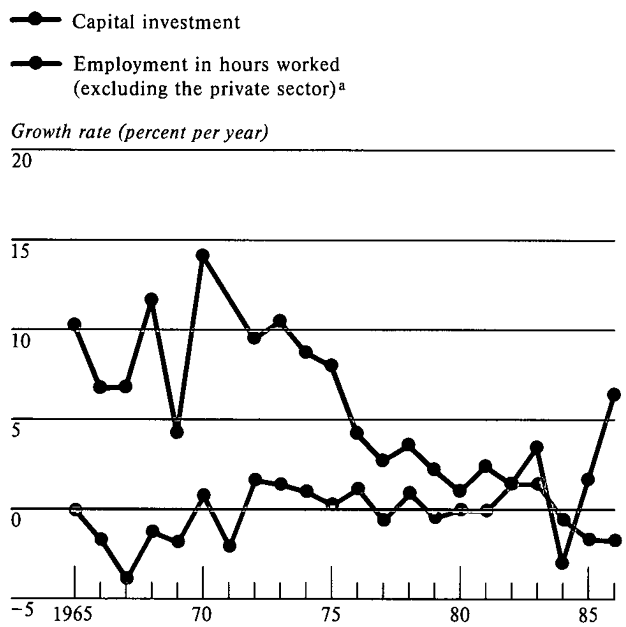
Figure 5
Growth of Capital Investment and Employment in Soviet Agriculture, 1965-86



[a] The USSR does not report statistics on hours worked in the private sector, but Western estimates have remained relatively stable during this time period.

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totaled 330 billion rubles, of which 61 percent represents nonresidential buildings and installations, 17 percent represents agricultural machinery and equipment, 3.8 percent represents transportation equipment, 0.5 percent represents draft animals, 9.5 percent represents productive livestock, and 4.6 percent represents perennial plantings.[3] But, while the overall size of the capital stock has been growing, the rate at which it is growing has been slowing since the mid-1970s (see figure 4). Growth of the stock of tractors in agriculture, for example, has fallen from about 3 percent per year in the mid-1970s to nearly zero in 1986.

Because technological advances in design and engineering are embodied in new capital, capital investment is the carrier of much of the new technology going into agriculture.[4] Growth of investment in agriculture fell from a high of 15 percent in 1971 to less than zero in 1984 (see figure 5). In 1986, however, investment growth rebounded to a rate approximately equal to that of the mid-1970s (6 percent).

[4] Capital investment in agriculture includes new machinery and equipment, new construction and installation of new farm buildings (including new livestock rearing facilities, irrigation and drainage systems, and agricultural research institutions), net additions to livestock, and capital repair.

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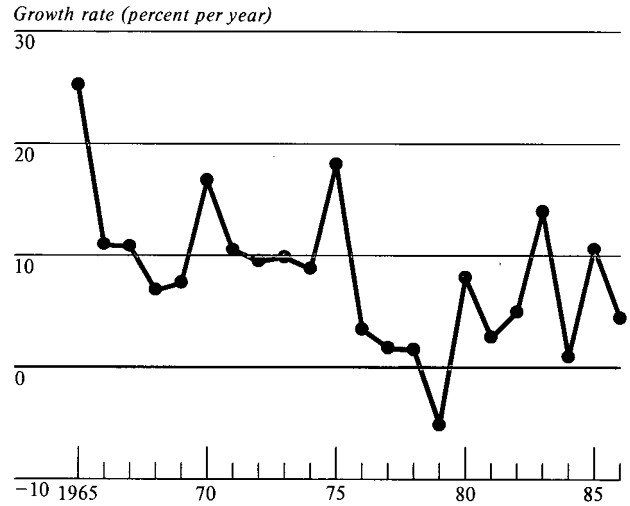
Labor. The size of the agricultural work force in the Soviet Union is shrinking slowly, as is its share of total employment in the economy as a whole. Over 35 million people are presently employed in agriculture, and many more engage in part-time farm work and gardening for personal consumption. During the 1970s there was little change in the size of the labor supply in terms of hours worked. Since 1984, however, agricultural employment has been decreasing at about 1 to 2 percent per year (see figure 5). Unless the Soviets do something to spur labor productivity, labor requirements in the future will exceed the supply and possibly result in a serious labor shortage in agriculture. Moscow has issued numerous decrees to improve the productivity of the farm labor force, but the decrees have not yet had a widespread positive effect.[5]

Material Inputs. Material inputs are produced by nonagricultural sectors of the economy for use in the agricultural sector, exclusive of capital investment goods. They include chemicals, fuels, electric power, animal feed supplements (including byproducts from food processing), and machinery spare parts.

Among the most important are manufactured fertilizers and agrochemicals. Aided by large imports of Western equipment and technology during the 1970s, the Soviet Union is presently the world's leading producer of manufactured fertilizers (nitrogen, phosphate, and potassium). Increases in crop yields since 1960 are directly attributable to the rapid growth in fertilizer deliveries. After 1975, however, growth of deliveries to agriculture slowed (see figure 6) because of lags in expanding production capacities and underutilization of existing capacities, which were caused by shortages of skilled labor, equipment failures, and transportation problems. Since 1979, growth of fertilizer deliveries has fluctuated at about half the rate of growth of the early 1970s.

Chemical control of insect pests, plant diseases, and weeds has also been an important factor in increased yields, particularly for grain. Since 1984 the Soviets have made special efforts to increase purchases of sophisticated forms of Western herbicides, insecticides, and fungicides. In contrast to fertilizers, more than half of the pesticides used in the USSR are imported from the West and from Eastern Europe. Although the use of chemical pesticides has increased in the Soviet Union, the average application rate is still far below that of Western countries.

Figure 6
Growth of Fertilizer Deliveries to Agriculture, 1965-86



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Technology. Technology in agriculture encompasses both enhancements to resources, such as new seed varieties and livestock breeds, and innovations in the way resources are used, such as crop rotation schemes and management of livestock facilities. The USSR pursues research and development in many areas of

[5] See Ann Goodman, Margaret Hughes, and Gertrude Schroeder, "Raising the Efficiency of Soviet Farm Labor: Problems and Prospects," in *Gorbachev's Economic Plans*, Volume 2 , U.S. Congress, Joint Economic Committee, Washington, DC: U.S. Government Printing Office, November 1987, pp. 100-124.

Agricultural Research in the USSR

As Moscow has learned, simply increasing supplies of physical inputs has not been sufficient to meet the growing demand for agricultural products. Increases in productivity are also required. Moscow has no direct control over productivity growth, and must depend in part on the diffusion of successful technological innovations. The USSR pursues research and development in many areas of farm production and is also incorporating modern aspects of Western agrotechnology in an attempt to improve productivity:

- Plant breeding. *Work on wheat breeding alone is carried out at nearly 50 institutions. The Soviet wheat breeding program maintains a germ-plasm collection that contains roughly 40,000 wheat specimens, probably the largest collection in the world.*

- Agrochemicals. *Advanced chemical fertilizers, growth stimulants, and pesticides specific to soil and climate conditions in the USSR are being developed. Facilities for producing modern agrochemicals are also being imported from the West.*

- New designs for agricultural machinery. *Soviet engineers are developing agricultural equipment suitable for tillage techniques needed to conserve moisture and prevent soil erosion, grain combines and other harvesting equipment to reduce losses during harvest, more energy efficient drying equipment, and controlled atmosphere storage.*

- Livestock research. *Soviet efforts in livestock breeding have focused on developing breeds of cattle and hogs that will be more efficient—more meat or milk per animal—and have higher reproduction rates. Research is also conducted on better methods for rearing livestock, such as ways to increase production, harvesting, storage, and utilization of livestock feed, improved animal shelters, and prophylactic care of animals.*

- Genetic engineering. *Soviet scientists are placing considerable attention on agricultural application of genetic engineering. Progress is occurring in development of hormones, protein supplements, antibiotics, and improved vaccines.*

farm production, including plant breeding, development of chemical fertilizers and pesticides, the design of agricultural machinery, livestock breeding, and genetic engineering (see inset).

According to Western scientists, agricultural research facilities in the USSR range from antiquated to state of the art. The Soviet Union is at least 10 to 15 years behind the West in developing and applying agrotechnologies. As in the rest of the economy, Soviet agriculture suffers from a serious lag between development of technology and its application. This condition is exacerbated in agriculture because of the lack of interdisciplinary teamwork. For example, Soviet plant breeders do not work closely with plant pathologists and entomologists. As a result, real technological progress is slow.

***Weather*.** Since a large part of Soviet farm production occurs in risk-prone areas, year-to-year fluctuations in weather conditions dramatically affect the volume of farm output. Most of the agricultural area has a generally harsh and variable climate. Only about 27 percent of the total land area of the USSR is suitable for farming. Of this, slightly more than one-third is arable; the remainder is in meadow, pasture, orchard, vineyard, or is idle.[6] More than half of this arable land lacks adequate and reliable moisture. In general, areas warm enough to foster plant growth tend to suffer from lack of moisture, and areas with sufficient moisture are predominantly located in the cold, northern latitudes where the growing season is short. Livestock production is less influenced by weather than crop production, but temperature extremes can

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have an adverse effect on animal health and productivity, and weather indirectly affects livestock production through its effect on feed availability.

Government Policy. Since the mid-1970s, government programs have emphasized productivity growth as a means to increase farm output and—at the same time—conserve on resources going to agriculture. Moscow has issued numerous decrees over the last decade that were intended to improve productivity and to reduce cost, waste, and the need for agricultural imports. Efforts have focused on labor incentives, planning and organization, changes in the management structure, and the restructuring of investment allocations within the agroindustrial complex. Since the initiation of the Brezhnev Food Program in mid-1982 and the recent campaign to "intensify" agriculture, the flow of fertilizers, pesticides, and other industrial goods to agriculture has accelerated, and more care has been taken to apply them where and when they would do the most good.

The Model

A mathematical model was developed to separate the effects of weather from the effects of other factors. Of the six broad categories listed above, capital, labor, weather, and productivity changes resulting from government policies are accounted for in the model explicitly. The capital stock variable serves as a proxy for the two remaining factors—material inputs and technological progress. The model predicts the value of net agricultural output, defined as the sum of the value of total crop production (less seed and waste) and the net value of livestock production (including inventory, excluding feed) measured in constant 1982 prices (see appendix B for a more complete definition).[7] The model is used to generate an historical output series that is adjusted for weather; to estimate economic gains and losses attributable to weather; to estimate the trend in agricultural growth owing to nonweather factors alone; and to evaluate prospects for meeting Soviet plan targets.

The model was developed as an aggregate production function for agriculture.[8] As in any aggregate production function, the factors of production are themselves gross aggregates. Capital is the value of the capital stock used in agriculture, excluding livestock. This includes the undepreciated value of all machinery and equipment, tools, vehicles, and value of buildings and structures, measured as a single input denominated in comparable rubles. Labor is total employment in agriculture—socialized and private—measured in man-hours with no regard to skill level or other aspects of labor quality. Similarly, the weather variables are also gross aggregates. Two weather variables are used in the model: the average winter temperature and the ratio of temperature to precipitation for late spring and early summer.

The model is

$$Q = \alpha_1 \alpha_2(W) \alpha_3(P) K^{\beta} L^{1-\beta} \varepsilon,$$

where Q is output; K and L are capital and labor inputs, respectively; β is the capital elasticity parameter; α_1 is a scale adjustment that reconciles the units of measure used for Q, K, and L; $\alpha_2(W)$ is the weather function; $\alpha_3(P)$ is a function that reflects potential productivity changes linked to changes in government policy; and ε is a stochastic error term.[9] With this model specification, the capital-labor ratio establishes the trend of agricultural output over time, while fluctuations about the trend caused by weather and changes in government policy are modeled by upward and downward shifts controlled by the functions $\alpha_2(W)$ and $\alpha_3(P)$. Appendix A includes a detailed discussion of the model development, and data used to fit the model are presented in appendix B.

[7] Previous models have been developed to evaluate prospects for grain production only. See Russell A. Ambroziak and David W. Carey, "Climate and Grain Production in the Soviet Union," in *Soviet Economy in the 1980s: Problems and Prospects*, Part 2, U.S. Congress, Joint Economic Committee, Washington, DC: U.S. Government Printing Office, December 1982, pp. 10-12.

[8] The model is currently used in CIA's macroeconomic model of the Soviet Union. See Robert L. Kellogg "Modeling Soviet Modernization: An Economy in Transition," *Soviet Economy*, 4,1: 36-56, 1988.

[9] Capital elasticity is the percentage change in output that results when capital is increased 1 percent, holding all other factors constant.

Modeling Policy and Productivity Changes

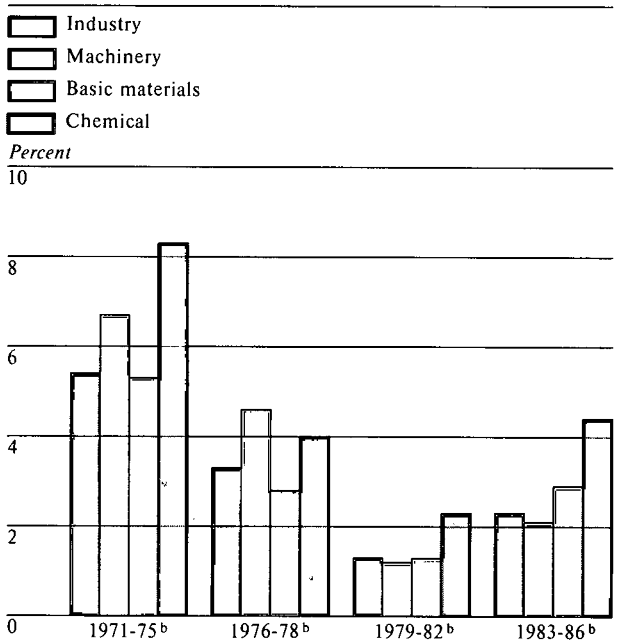
The function $\alpha_3(P)$ was created to reflect relative changes in productivity due to government policy actions.[10] In a centrally planned economy like the Soviet Union, productivity changes arise either directly or indirectly as a result of government policy actions. However, modeling the impact of government activity is difficult because—unlike weather, capital, and labor—policy variables cannot be measured. Nevertheless, a subjective estimate can be made of the *relative changes in productivity* expected from government policies.

The function $\alpha_3(P)$ was developed in this way to reflect the likely impact on agriculture of government policies and programs for the economy as a whole as well as for specific programs in agriculture. The 1968-78 period was selected as the base period, and productivity changes for 1979-87 were modeled relative to this base. It was thus assumed that productivity growth arising from changes in government policy during 1968-78 was fairly steady year to year. Most of this period was free of sharp policy changes in agriculture.[11]

Beginning in 1976, however, Moscow attempted to shift from an extensive growth pattern to an intensive growth strategy for the economy as a whole. In doing so, it precipitated the 1976-82 industrial growth slowdown.[12] The problems in industry—including those sectors supporting agriculture—were most severe during 1979-82 (see figure 7). In addition, transportation organizations were increasingly unable to keep pace with the growing requirements for timely deliveries of industrial goods to farms and for shipping farm products to processors.[13] As a result, growth of deliveries of goods and services to agriculture lagged (see table 1). A statistical test determined that factors other than capital, labor, and weather were responsible for a growth slowdown in agriculture during 1979-82, similar to that observed for industry, suggesting that the problems in industry extended to agriculture as well (see inset).

But the slowdown in growth of deliveries from industry was not the only policy-related factor affecting agriculture during this period. It was clear that government policies specific to agriculture were flawed:

Figure 7
Industrial Growth by Sector, 1971-86[a]



[a] Based on estimates of value added at 1982 factor cost.
[b] Average annual growth rates.

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[10] The general concept of productivity—increased output with no change in the quantity of inputs used—is appealed to in this context. The productivity measure to which this concept best corresponds is total factor productivity (see subsection, "Total Factor Productivity Adjusted for Weather").
[11] See David M. Schoonover, "Agriculture and the Grain Trade—Overview," in *Soviet Economy in the 1980s: Problems and Prospects*, Part 2, Joint Economic Committee, Congress of the United States, December 1982, pp. 1-6.
[12] See Gertrude E. Schroeder, "The Slowdown in Soviet Industry, 1976-82," *Soviet Economy* 1,1:42-74, January-March 1985.
[13] See Judith Flynn and Barbara Severin, "Soviet Agricultural Transport: Bottlenecks To Continue," in *Gorbachev's Economic Plans*, Volume 2, U.S. Congress, Joint Economic Committee, Washington, DC: U.S. Government Printing Office, November 1987, pp. 62-78.

Table 1
Average Annual Growth Rates of Selected Inputs to Agriculture

Percent

	10-Year Period Before Growth Slowdown (1969-78)	Growth Slowdown Period (1979-82)	Recovery and Post-Slowdown Period (1983-86)
Capital investment	8.2	1.7	2.1
Tractor deliveries to agriculture	2.3	−1.4	3.1
Grain combine deliveries to agriculture	2.0	0.0	0.2
Current purchases [a]	5.6	2.7	5.0
Fertilizer deliveries to agriculture [b]	10.1	2.6	7.4
Nitrogen	11.4	4.4	6.4
Phosphate [c]	8.5	3.8	8.6
Potassium	10.6	−1.3	8.0

[a] Current purchases include chemical fertilizers, electric power, fuel and lubricants, machinery repair, and animal feed supplements. Capital investment goods are not included in current purchases.
[b] Included are a small amount of nutrients used in feed additives.
[c] Phosphate fertilizers include ground phosphate rock.

- Investment resources going to agriculture were wastefully allocated and inefficiently utilized. The construction of livestock facilities had been overemphasized, for instance, while the share of investment allocated to rural housing was cut. Soviet authors have complained, moreover, about losses of agricultural products (20 to 25 percent) because construction of storage facilities and rural roads was neglected.

- Agricultural machinery downtime increased, efficiency in the use of inputs—especially machinery, equipment, and fertilizers—declined, and growth in livestock herds outstripped growth in feed availability.[14]

[14] See Barbara Severin, "Solving the Soviet Livestock Feed Dilemma: Key to Meeting Food Program Targets," in *Gorbachev's Economic Plans*, Volume 2, U.S. Congress, Joint Economic Committee, Washington, DC: U.S. Government Printing Office, November 1987, pp. 45-61.

Testing for the Effects of the Industrial Growth Slowdown on Soviet Agricultural Performance

In developing the model, it became clear that weather factors alone were not sufficient to explain agriculture's dismal showing during the 1979-82 period. A statistical test was devised to determine if the industrial growth slowdown had a depressing effect on Soviet agriculture independent of capital and labor inputs and weather factors. The test was conducted by replacing the function $\alpha_3(P)$ by a dummy variable, which consisted of 1's for the years 1979-82 and 0's for all other years, and reestimating the model. The results revealed that the coefficient for the dummy variable was highly significant statistically and had a negative sign, suggesting that the slowdown in agriculture during this period was associated with the industrial growth slowdown and may have been caused by it at least in part.

- Producing and marketing farm products was becoming increasingly more difficult to synchronize as the size and interdependence of the economy increased.

As the difficulties in agriculture intensified, Moscow promulgated new policies in attempts to reverse the decline in productivity. The Brezhnev Food Program of May 1982 was the most comprehensive of these measures (see inset). Although the Food Program resulted in some improvements in productivity, it fell short of the desired results.[15] Since Brezhnev's death in late 1982, Gorbachev has used his influence in the leadership to reshape the program to reflect more closely his own views and priorities. His most recent strategy to motivate the individual farmworker has

[15] See Penelope Doolittle and Margaret Hughes, "Gorbachev's Agricultural Policy: Building on the Brezhnev Food Program," in *Gorbachev's Economic Plans*, Volume 2, U.S. Congress, Joint Economic Committee, Washington, DC: U.S. Government Printing Office, November 1987, pp. 26-44.

The Brezhnev Food Program

The Brezhnev Food Program was unveiled in May 1982. Key features of the program included:

- *"Unified management" of food production, which ultimately resulted in the establishment of the State Agroindustrial Committee, Gosagroprom, in November 1985.*
- *Reallocation of investment resources within the agroindustrial complex to upgrade the system for handling, storing, and processing food and to improve housing and living conditions in the countryside.*
- *An increase in financial as well as nonmonetary incentives intended to attract skilled workers to agriculture and encourage workers from southern, labor-surplus regions to resettle in northern areas, where labor is insufficient to meet demand.*

been to expand the use of the collective contract, which organizes workers into teams operating under contract to the farm and pays them on the basis of what they actually produce. A deadline of December 1988 was set for transferring all farm labor to the collective contract system.

In addition to measures targeted at increasing worker productivity, Gorbachev has given the "intensive technology" program a high priority. Intensive technology, as defined by the USSR, includes many practices routinely performed in the West—use of high-yield varieties, planting after fallow where possible, implementing efficient field operation schedules, and extensive use of agrochemicals. The program commenced in 1984 on selected test sites scattered over the Soviet Union. Intensive technology practices were increased to include almost 17 million hectares in 1985, and expanded again in 1986 to about 30 million hectares. In 1987 the intensive technology area included 35 million hectares, and plans call for the program to encompass 50 million hectares by 1990.

Table 2
Comparison of Actual Data to Model Predictions

Year (t)	Farm Output *(billion rubles)*		Annual Growth Rates *(percent)*	
	Actual (Q_t)	Predicted ($\tilde{Q}_t$)	Actual (Q_t/Q_{t-1})	Predicted ($\tilde{Q}_t/Q_{t-1}$)
1968	105.061	106.393	6.1	7.4
1969	100.303	100.732	−4.5	−4.1
1970	112.535	112.464	12.2	12.1
1971	111.388	110.707	−1.2	−1.6
1972	104.660	104.986	−6.0	−5.7
1973	121.807	119.841	16.4	14.5
1974	119.629	121.073	−1.8	−0.6
1975	109.410	109.094	−8.5	−8.8
1976	118.060	114.802	7.9	4.9
1977	122.829	123.288	4.0	4.4
1978	126.605	125.758	3.1	2.4
1979	118.927	120.991	−6.1	−4.4
1980	113.740	113.732	−4.4	−4.4
1981	112.500	111.332	−1.1	−2.1
1982	120.788	120.174	7.4	6.8
1983	128.638	130.706	6.5	8.2
1984	128.046	129.277	−0.5	0.5
1985	125.992	127.435	−1.6	−0.5
1986	136.287	134.448	8.2	6.7
1987	132.032 [a]	131.575 [b]	−3.1	−3.5

[a] Preliminary.
[b] The predicted value for 1987 was obtained by assuming that the trend in employment growth during 1984-86 continues through 1987.

These policy changes were captured in the function $\alpha_3(P)$ by a variable named PRODCHNG (see appendix A for the complete functional form of the model). PRODCHNG was defined subjectively so as to reflect the relative impact that changes in government policies since 1978 might have had on productivity growth in agriculture. The variable PRODCHNG was assigned a value of zero for the 1968-78 base period. For 1979, the variable was assigned a value of −1 to simulate a decrease in productivity growth relative to the base period as the industrial growth slowdown and flawed agricultural policies began to affect production. The variable was assigned the values −2 in 1980 and −3 in 1981 and 1982 to

Table 3
Decomposition of the Model Into Functional Components and Calculation of Weather-Adjusted Output

	α_1	$\alpha_2(W)$	$\alpha_3(P)$	K^β	$L^{1-\beta}$	ε	$\tilde{Q}$	Q	Q*
1968	1.6607	0.9934	1.0000	2.0094	32.0931	0.98748	106.393	105.061	105.757
1969	1.6607	0.9468	1.0000	2.0404	31.3971	0.99574	100.732	100.303	105.939
1970	1.6607	1.0348	1.0000	2.0646	31.6964	1.00064	112.464	112.535	108.749
1971	1.6607	1.0155	1.0000	2.1006	31.2490	1.00615	110.707	111.388	109.685
1972	1.6607	0.9448	1.0000	2.1378	31.2962	0.99690	104.986	104.660	110.766
1973	1.6607	1.0523	1.0000	2.1756	31.5175	1.01640	119.841	121.807	115.747
1974	1.6607	1.0382	1.0000	2.2172	31.6691	0.98807	121.073	119.629	115.221
1975	1.6607	0.9254	1.0000	2.2612	31.3897	1.00290	109.094	109.410	118.221
1976	1.6607	0.9661	1.0000	2.3014	31.0878	1.02839	114.802	118.060	122.192
1977	1.6607	1.0177	1.0000	2.3333	31.2610	0.99627	123.288	122.829	120.685
1978	1.6607	1.0171	1.0000	2.3679	31.4398	1.00674	125.758	126.605	124.472
1979	1.6607	1.0188	0.9523	2.4003	31.2821	0.98294	120.991	118.927	116.730
1980	1.6607	0.9912	0.9069	2.4306	31.3409	1.00007	113.732	113.740	114.749
1981	1.6607	1.0041	0.8637	2.4611	31.4058	1.01050	111.332	112.500	112.040
1982	1.6607	1.0542	0.8637	2.4899	31.9163	1.00511	120.174	120.788	114.578
1983	1.6607	1.0169	0.9523	2.5206	32.2409	0.98418	130.706	128.638	126.500
1984	1.6607	0.9571	1.0000	2.5479	31.9192	0.99048	129.277	128.046	133.780
1985	1.6607	0.9506	1.0000	2.5707	31.3996	0.98867	127.435	125.992	132.537
1986	1.6607	0.9589	1.0500	2.5925	31.0107	1.01368	134.448	136.287	142.117
1987	1.6607	0.9460	1.0500	2.6135	30.5171	1.00347	131.575	132.032	139.566

Note: $\tilde{Q}$ represents the model predictions for farm output, and is equal to $\alpha_1\alpha_2(W)\alpha_3(P)K^\beta L^{1-\beta}$. Q is actual farm output, also equal to $\tilde{Q}\varepsilon$. Farm output after adjusting for weather is Q*, equal to $Q/\alpha_2(W)$.

simulate a worsening situation. Under the assumption that the Brezhnev Food Program and subsequent programs helped to reverse the decline in productivity growth, PRODCHNG was assigned the values −1 in 1983 and zero again in 1984 and 1985. To simulate gains from the intensive technology campaign in 1986 and 1987, PRODCHNG was given the value +1 for these two years.[16]

Applications of the Model

Weather-Adjusted Output

After incorporating the function $\alpha_3(P)$ as derived above into the model, model parameters were estimated using historical data for 1968 through 1986.[17] The model fits the historical data quite well (see figure 1), and even predicts historical growth rates closely (see table 2). All variables were statistically significant at the 0.0001 level (that is, the probability of falsely rejecting the null hypothesis that a parameter is zero is less than 1 in 10,000). In addition to statistical significance, the signs of the parameters all matched a priori expectations. Time series of the functional components of the model are presented in table 3, and

[16] There is *potential* for multicolinearity between the functions $\alpha_2(W)$ and $\alpha_3(P)$. If this were the case, it would not be possible to distinguish the effects of weather from policy-related declines in productivity during the 1979-83 period. Analysis included in appendix A, however, demonstrates that there is no empirical evidence that multicolinearity is a problem in this case.

[17] Data for 1987 were not used to estimate parameters because reliable estimates of employment were not available. Weather data for 1987 and capital available at the beginning of the year were available and were used in conjunction with the model to calculate a model prediction for 1987, which was very close to the preliminary estimate of farm output for 1987 (see table 2).

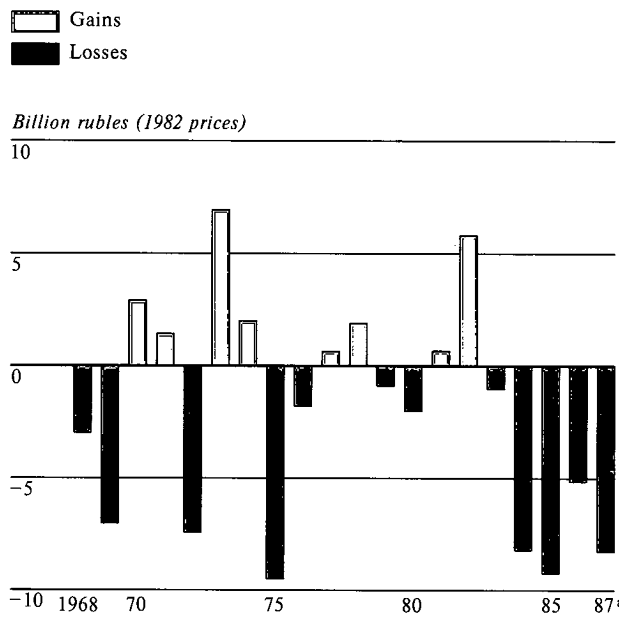
An Economic Measure of the Effects of Weather on Soviet Agricultural Performance

One way to measure the effects of weather on agricultural production is to estimate output for each year using "average" weather data and contrast it to model predictions made using actual weather data. Output corresponding to "average" weather was determined by solving the model using the mean values of the two weather variables. These mean values were based on weather data for the past 20 years.

Comparison of the "average-weather" predictions to "actual weather" predictions reveals how much loss or gain may have occurred each year as a result of weather effects alone (see figure 8). Overall, losses exceeded gains by 41.3 billion rubles over the 20-year period. Weather-related losses in excess of 2 billion rubles occurred in eight of the 20 years, whereas weather-related gains of more than 2 billion rubles occurred in only three years. These results suggest that weather-related losses can be expected to occur more frequently than weather-related gains.

Significant weather-related losses were estimated for each of the last four years (1984-87). Two of the years—1985 and 1987—were among the three coldest winters in the last 20 years, and the two remaining years (1984 and 1986) were among the five years with the hottest and driest conditions during spring and early summer (April-July) (see appendix B).

Figure 8
Estimated Agricultural Losses and Gains Due to Weather, 1968-87



[a] Preliminary.

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statistical properties of the model parameters are presented in appendix A.

The model can be used to isolate the effects of weather on agricultural production, and thus reveal the relationship between farm output and nonweather factors. One approach is to solve the model using "average" weather and compare the results to actual performance (see inset). The approach taken here was to *adjust* the output series for weather, thereby creating a "weather-adjusted" measure of farm output. This weather-adjusted series, Q*, was derived by dividing actual output by the model's prediction of the year-to-year fluctuations that are due to weather, as follows (also see table 3):[18]

$$Q^* = \frac{Q}{\alpha_2(W)}$$

[18] Actual output (Q) is represented algebraically by the model as follows:

$$Q = \alpha_1 \, \alpha_2(W) \, \alpha_3(P) \, K^{\beta} \, L^{1-\beta} \, \varepsilon,$$

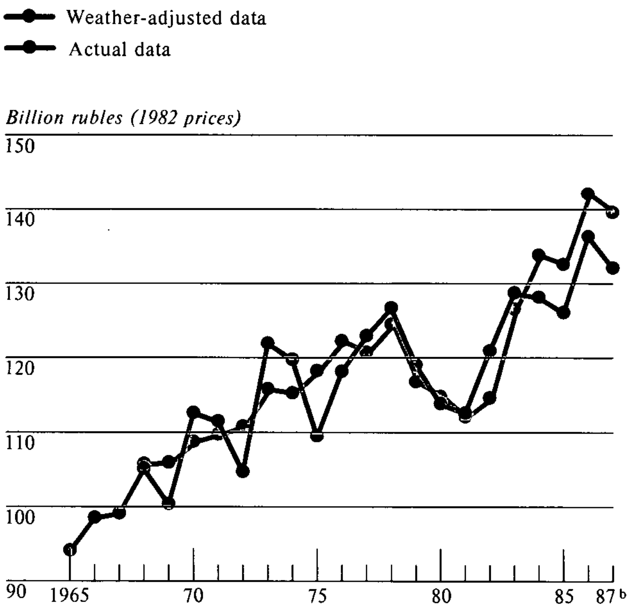
If both sides of the equation are divided by the weather function, α_2 (W), we have

$$\frac{Q}{\alpha_2(W)} = \frac{\alpha_1 \, \alpha_2(W) \, \alpha_3(P) \, K^{\beta} \, L^{1-\beta} \, \varepsilon}{\alpha_2(W)},$$

which simplifies to

$$\frac{Q}{\alpha_2(W)} = \alpha_1 \, \alpha_3(P) \, K^{\beta} \, L^{1-\beta} \, \varepsilon = Q^*$$

Figure 9
Weather-Adjusted Farm Output, 1965-87[a]



[a] Net of feed, seed, and waste.
[b] Preliminary

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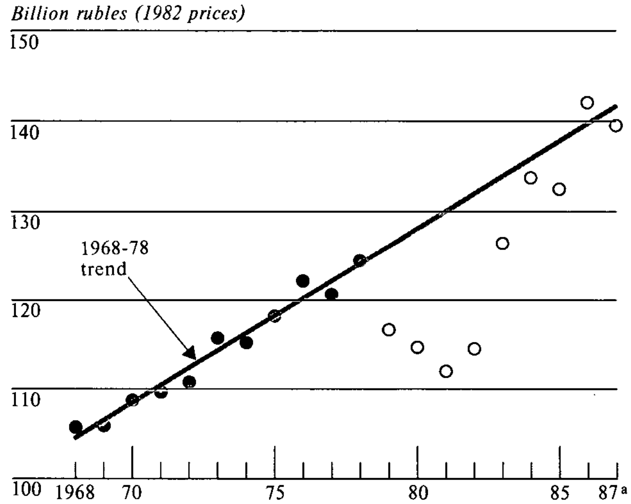
Figure 10
Long-Run Trend in Farm Output After Adjusting for Weather, 1968-87



Note: Closed circles denote the time series used to calculate the trend.
[a] Preliminary

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This adjustment for weather is similar in concept to the seasonal adjustment applied to many Western economic aggregates, except that the "season" extends through 20 years. Because the adjustment uses only weather variables, the resulting series retains year-to-year changes stemming from the growth of inputs—capital, labor, and material—as well as productivity growth, including technological progress and "human factor" effects. The weather-adjusted series is contrasted with actual farm output in figure 9.

The pattern of year-to-year changes in weather-adjusted output corresponds to changes in government policy (see figure 10). The 1968-78 period is marked by a steady—although very gradual—increase in output, reflecting relatively stable growth of inputs, steady but slow technological progress, and the absence of sharp swings in government policy. A departure from this pattern became apparent in 1979, when weather-adjusted output dropped precipitously. Weather-adjusted output continued to fall through 1981 and showed only slight improvement in 1982. This slump in agriculture corresponds to the worst of the industrial growth slowdown period, discussed previously. In 1983, however, there was a remarkable recovery, possibly reflecting improvements in efficiency stemming from enactment of the Brezhnev Food Program the previous year. By 1984, performance had nearly returned to the pre-1979 trend, and performance was clearly back on trend again in 1986 and 1987.[19]

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[19] This relationship between weather-adjusted farm output and nonweather factors is not dependent on $\alpha_3(P)$. Nearly identical results were obtained when model parameters were reestimated after dropping $\alpha_3(P)$ from the model and excluding the 1979-82 period from the dataset (see appendix A for more details).

The rate at which weather-adjusted output is increasing has important ramifications for Gorbachev's agriculture policy. The long-run trend in weather-adjusted output was measured by regressing weather-adjusted output against time for the 1968-78 period. The regression equation is (standard errors in parentheses):

$$\text{weather-adjusted output} = \underset{(.817536)}{102.61668} + \underset{(.12054)}{1.94925} \times t$$

where t is time in years (t = 1 for 1968). This equation estimates that weather-adjusted farm output has been increasing only 1.9 billion rubles per year. Although 1984-87 were not included in the regression, weather-adjusted output in these years conforms closely to the pre-1979 trend (see figure 10). This gain in output is nearly offset by increased costs of inputs. For example, assuming no changes in the growth of labor and capital or changes in productivity growth, the Soviets will have to spend about 1.3 billion rubles in current purchases alone to obtain the additional 1.9 billion rubles of weather-adjusted output.[20]

Returns to Capital and Labor

The model estimates the return to capital in agriculture by the parameter β—the capital elasticity parameter. The capital elasticity was estimated to be 0.17 percent, indicating that a 1-percent increase in capital produces only a 0.17-percent increase in farm output, holding all other factors constant.[21] This measure of the capital elasticity represents the average

[20] This analysis is based on the judgment that, in order to sustain weather-adjusted output growth at the 1968-78 trend, growth of all inputs—including current purchases—must also be sustained. The pre-1979 trend for the value of current purchases increased about 1.3 billion rubles per year. The time trend equation is

$$\text{Purchases from other sectors} = 19.13366 + 1.281733 \times t,$$

where t is time in years (t = 1 for 1969).

[21] The parameter β can also be interpreted as the relative share of the total output contributed by capital. According to this estimate of β, capital accounts for 17 percent of the value of farm output. Using a different estimation method, Diamond and Krueger ("Recent Developments in Output and Productivity in Soviet Agriculture," in *Soviet Economic Prospects for the Seventies*, US Congress, Joint Economic Committee, Washington, D.C.: US Government Printing Office, June 1973, p. 329) estimated the relative share of capital in total output to be 15 percent.

Table 4
Capital Elasticity Estimates for Agriculture and Other Producing Sectors [a]

Sector	Capital Elasticity (β)
Industry	
Industrial materials	.455
Machine building	.523
Chemicals	.728
Consumer goods	.423
Fuels	.039
Electric power	.892
Construction	.286
Transportation and communications	.330
Domestic trade and other	.175
Farm output [b]	.168

[a] The capital elasticity parameters were estimated by fitting a modified Cobb-Douglas production function with data on capital, labor, and output for 1969-85 (see Kellogg, op. cit.). The general form of the production function was:

$$Q = \alpha(t)\, K^{\beta} L^{1-\beta}$$

where

Q = output measured in 1982 rubles at factor cost
K = average capital stock in 1973 rubles
L = employment in man-hours
α(t) = scale adjustment and adjustment for 1976-82 industrial growth slowdown period
β = capital elasticity

[b] Output for all groups except agriculture is measured in value-added units. Output for agriculture is not value added, since it includes the value of purchases from other sectors (such as fuels and agrochemicals). Thus, the agricultural capital elasticity is not completely comparable to the others. Since the value of purchases from other sectors has been growing faster than the value of farm output, the capital elasticity in value-added terms would be smaller than reported here.

The Don Combine—An Attempt To Increase Farm Productivity Through Capital Investment

Even though the return to additional capital has been low in agriculture, it may still be rational to attempt to boost farm output by increasing capital investment. If old machinery and equipment were replaced by the right kinds of modern, efficient farm machinery, it would theoretically be possible to increase the return to the new capital substantially above returns registered in the past. However, the Soviet system seems incapable of making such gains very quickly or easily. Consider, for example, the case of the Don grain combine.

Soviet planners in the late 1970s assigned top priority to modernizing the fleet of grain harvesting combines. Their intent was to replace their obsolete fleet of combines—which prolonged the harvest period and lost substantial quantities of grain during harvesting—with new, modern combines. The new Don 1500 combine, which was to be 50 to 70 percent more productive than existing models, was designed for use not only for harvesting grain, but also for harvesting seed grasses, soybeans, sunflower seeds, and corn. In his report to the 27th Party Congress, Gorbachev claimed that the use of this machine in the 12th FYP period would reduce grain losses by millions of metric tons and eliminate the need for 400,000 machine operators, equal to nearly 15 percent of the present force.

Under development since the late 1970s, the Don was put into series production in September 1986. Problems in manufacture and delivery have been extensive, however, and the Don thus far has had little positive impact on grain harvesting:

- *Design flaws made initial models too heavy to operate in any but the most ideal ground conditions. In subsequent models, engine horsepower was increased and the weight reduced from 18 tons to 13 tons.*
- *Parts for the Don were supplied by 500 separate industrial enterprises, and many deliveries were late. Moreover, the quality of component parts was low; tests in 1986 showed that 80 percent of breakdowns were due to flaws in parts and accessories.*
- *The first large shipment to consumers in June 1987—3,000 combines—consisted largely of machines that were missing accessories and parts. At least half had no headers for cutting crops and were therefore useless.*

Nor have Soviet farmers been favorably impressed with the Don. A July 1987 Pravda *article stated that users were finding the Don too heavy, too costly, and too complicated to operate and repair. One collective farm official complained that, of the 18 Dons purchased by his farm, only seven were operating—the rest had been cannibalized for parts.*

return to additional capital over the past 20 years. By this measure, the return to capital in agriculture is lower than in any other productive sector of the Soviet economy except the fuels branch of industry (see table 4). Estimates of capital elasticities in industry (excluding the fuels sector) are roughly three to five times as great as in agriculture. Some of the reasons for the low return to capital are revealed in the difficulties the Soviets have had introducing a new, modern fleet of grain combines (see inset).

The return to labor in agriculture, on the other hand, is over four times higher than the return to capital. The labor elasticity is estimated to be 0.83 (one minus the capital elasticity). Unlike capital, however, the labor input is gradually declining. Thus, the high return to labor works to the Soviets' disadvantage. That is, a 1-percent decline in agricultural employment (holding other inputs constant) produces a 0.83-percent decline in farm output, which represents a substantial marginal loss.

Table 5
Derivation of Total Factor Productivity Index

	Value-Added Weather-Adjusted Output Index	Capital Index (K_I)	Labor Index (L_I)	Combined Inputs		Factor Productivity	
				Index	Annual Growth Rate (*percent*)	Index	Annual Growth Rate (*percent*)
1968	1.000	1.000	1.000	1.000		1.000	
1969	0.993	1.095	0.973	0.993	−0.64	1.000	0.03
1970	1.018	1.174	0.985	1.015	2.16	1.003	0.32
1971	1.018	1.301	0.968	1.018	0.33	1.000	−0.33
1972	1.015	1.444	0.970	1.038	1.94	0.978	−2.16
1973	1.055	1.603	0.978	1.064	2.51	0.992	1.38
1974	1.033	1.793	0.984	1.089	2.42	0.948	−4.44
1975	1.050	2.015	0.973	1.101	1.11	0.953	0.55
1976	1.104	2.238	0.962	1.110	0.82	0.994	4.31
1977	1.059	2.428	0.968	1.132	1.96	0.935	−5.92
1978	1.097	2.650	0.975	1.156	2.08	0.949	1.48
1979	1.005	2.873	0.969	1.166	0.87	0.861	−9.22
1980	0.972	3.095	0.971	1.183	1.46	0.821	−4.65
1981	0.932	3.333	0.974	1.200	1.48	0.776	−5.49
1982	0.949	3.571	0.993	1.234	2.82	0.769	−0.96
1983	1.059	3.841	1.005	1.262	2.27	0.838	9.05
1984	1.128	4.095	0.993	1.263	0.09	0.893	6.49
1985	1.096	4.317	0.974	1.254	−0.74	0.873	−2.18
1986	1.186	4.539	0.959	1.249	−0.39	0.949	8.71
1987	1.149	4.761	0.941	1.239	−0.79	0.926	−2.40

Sources: The value-added, weather-adjusted output index is from appendix B, table B-5. The capital index was obtained by dividing beginning-of-year capital by the value for 1968 (see table B-1 for original capital series). The labor index was obtained by dividing average annual agricultural employment by the value for 1968 (see table B-3 for original employment series). The combined inputs index was calculated as $K_I^{.17}L_I^{.83}$. The total factor productivity index was calculated by dividing the output index by the combined inputs index.

Note: The combined inputs index included only capital and labor because the model provided estimates of the factor shares—17 percent for capital and 83 percent for labor. Current purchases—representing material inputs such as fuels and agrochemicals—were subtracted from gross output prior to the calculation. Land was excluded from the calculation entirely; however, much of the increase in the services from land in the last 20 years is included in capital because of the huge capital investment expenditures allocated to land reclamation.

These results demonstrate why the Soviets are concerned about productivity in agriculture. The structure of the model implies that Moscow has three potential policy options for increasing farm production: increase the capital stock by accelerating growth in capital investment; increase the number of workers and/or hours worked per worker, including increases in the number of part-time workers; and increase productivity. The low return to capital relative to alternative investments in other sectors of the economy suggests that increasing capital investment in agriculture is not in the best interest of the overall economy. Increasing the labor input is not feasible, because the size of the labor force in agriculture is declining as a result of natural demographic trends, which Moscow is powerless to change, and the leadership is opposed to increasing part-time employment in agriculture at the expense of production in other sectors of the economy. The only remaining policy option is to increase the *productivity* of the inputs, in particular, the productivity of farmworkers.

Total Factor Productivity Adjusted for Weather

Productivity can be measured in several ways. The measure used extensively by the Soviets is labor productivity, which is estimated by dividing total output by the labor used to produce it. This approach can be misleading, however, because it fails to account for the capital cost. Another measure is capital productivity, determined as the ratio of output to the value of the capital used to produce it. Similarly, capital productivity ignores labor as a source of productivity.

Total factor productivity is a measure that accounts for both capital and labor growth. It is calculated by dividing total output by a measure of *combined* inputs, as follows:

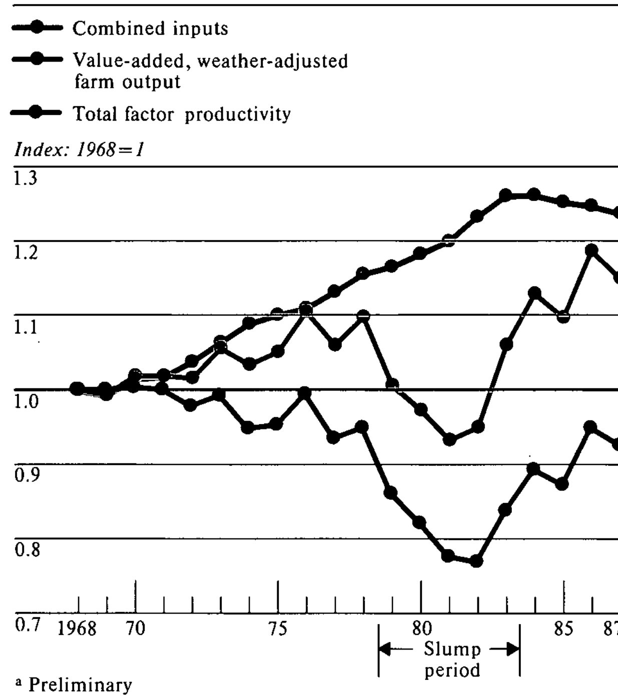
$$\text{total factor productivity} = \frac{Q}{K^{\beta} L^{1-\beta}},$$

where Q, K, and L are indexes (with the same base year) for value-added output, capital, and labor, respectively, and β is capital's share of total output. By definition, then, total factor productivity growth includes all sources of output growth other than increases in labor and capital, including: technological progress, human factor effects, labor quality changes, capital quality changes not reflected in the measurement of capital, and even gains and losses attributable to the weather.

For agriculture, it is useful to refine the calculation further by adjusting for weather so that productivity from remaining sources can be examined. This was accomplished by substituting the weather-adjusted output series—Q*—for Q in the above equation (see table 5). Adjustment of Q* to a value-added measure was made according to the method presented in appendix B. The model's estimate of β—17 percent—was used as the relative share of capital.

This weather-adjusted measure of total factor productivity reveals that the Soviets have made respectable gains in agricultural productivity in recent years—the annual growth rate for total factor productivity for 1984-87 averaged 2.7 percent (see figure 11). Not only has weather-adjusted output been increasing since 1982, but the growth of combined inputs (capital and labor) leveled off in 1983 and 1984 and has since been gradually declining. Since input growth is likely to continue to slow, further gains in productivity will be required to maintain or increase output growth.

Figure 11
Total Factor Productivity in Soviet Agriculture, 1968-87



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Prospects for the Future: Can the 1986-90 Plan Still Be Met?

The goal for Soviet agriculture as stated in the 12th Five-Year Plan (FYP) is "that the average annual volume of agricultural output in 1986-90 should be

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increased by 14.4 percent over the previous five-year period." [22] In terms of the output measure used in this study, a 14.4-percent increase represents an average output of 140.9 billion rubles per year, which substantially exceeds expectations based on past performance.[23] Average production in 1986 and 1987—134.2 billion rubles—was well below the goal (see inset). If the Soviets are to meet their FYP goal, output during 1988-90 must average 145.5 billion rubles.

The model was used to evaluate prospects for meeting the plan goal. Farm output for 1988, 1989, and 1990 was projected after making assumptions about capital and labor growth and simulating alternative outcomes for weather and government policy.

Assumptions

Capital. The growth of capital for 1988-90 is assumed to be 5 percent per year, equal to the average for 1985 and 1986, the most recent years for which data are available. This level of growth corresponds to what would be expected if investment in agriculture continued at about the same level as in 1986, 33.5 billion rubles per year, and there was no reduction in the retirement rate.[24]

Labor. Projections of employment in agriculture are more uncertain. A decline in the work force is expected, but how fast it will decline is hard to predict:
- Overall population growth has slowed to less than 1 percent per year.
- The working-age population of the European republics of the USSR is actually declining and will continue to do so through 1995.

[22] "Supreme Soviet Decree on Economic Development," published in *Izvestiya*, morning edition, 20 June 1986, p. 1.
[23] The average farm output for 1981-85 was 123.19 billion rubles. If average annual output is to increase by 14.4 percent in 1986-90, output would have to average 140.90 billion rubles per year.
[24] Because of the emphasis Moscow is placing on other components of the agroindustrial complex, and the slow but downward trend in capital growth in recent years, holding capital growth steady at 5 percent per year may be optimistic. However, reasonable assumptions about slower rates of capital growth had negligible effect on the projection because of the low return to capital.

Soviet Farm Production in 1986 and 1987: Not Enough Progress To Meet the Growing Demand

Agricultural performance during the first two years of the 12th FYP showed considerable improvement over previous years. Average farm output during 1986 and 1987 was about 5 percent above the average for 1983-85. The biggest gains were obtained in the production of grain, sunflower seeds, and livestock products:
- *Grain output for 1986-87 was nearly 14 percent higher than during 1983-85, exceeding 210 million metric tons each year.*
- *Production of sunflower seeds—the USSR's main source of vegetable oil—was 15 percent higher than during 1983-85.*
- *Meat output was 9 percent higher, and milk and egg production were each 5 percent higher than in 1983-85.*

Production of other major crops, however, was disappointing: production of potatoes and sugar beets increased only slightly, and output of cotton, vegetables, and fruit actually declined.

Nonetheless, the improvement in performance was not sufficient to satisfy consumers. The excess demand for food was fueled by government policies that steadily increased disposable income but maintained stable, relatively low, retail prices for food. Per capita disposable income grew by about 6 percent during 1986-87 compared with 1983-85, while overall per capita availability of farm products increased only slightly. By 1987, complaints of shortages in state retail food stores were common; reports of rationing of meat and butter had increased; and, in Moscow, collective farm market prices—which are relatively free to respond to supply and demand—had risen to record levels.

- Migration of agricultural workers—especially skilled labor and the young—to industry is continuing largely as a result of better living standards in urban areas.
- The share of elderly people in the rural populations of the European republics and the Russian Republic (RSFSR) is increasing.

Employment in agriculture declined 2 percent in 1985 and 1.5 percent in 1986. On the basis of 12th FYP goals for output and labor productivity for socialized farming, a "planned" rate of decline for labor in socialized agriculture of about 1.5 percent per year can be inferred.[25] For making projections, this "planned" rate of decline was applied to total agricultural employment.

Weather. The uncertainties of weather were formally incorporated into the analysis with stochastic simulation (also called Monte Carlo analysis). Information about the frequency with which *past* weather events occurred was used to generate frequency distributions for the weather variables specified in the model. Using these probabilities, agricultural output was predicted for each year by randomly choosing values for the weather variables according to a normal distribution with the appropriate mean and variance.[26] The model was solved repeatedly (5,000 times), drawing different values for the weather variables each time, producing a probability distribution of the output. A "most likely" range estimate was then derived from the probability distribution of the estimated output, reflecting the likelihood of all possible weather outcomes. For this study, the most likely range is defined such that there is a 10-percent chance growth could be below the lower limit of the range and a 10-percent chance it could exceed the upper limit.

[25] The 12th FYP called for growth of labor productivity in socialized agriculture to be 21.4 percent higher in 1986-90 than in 1981-85. Attainment of both the labor productivity and output growth goals given the results for 1986 implies that employment must average 59.9 billion man-hours per year during 1987-90. Assuming an exponential rate of decline, this is equivalent to an average annual growth rate of about −1.5 percent for 1987-90.

[26] Since the two weather variables have been correlated historically (when one is high the other tends to be high as well), a similar degree of correlation was incorporated into the simulations.

Material Inputs and Technology. Although purchases of material inputs are not explicitly accounted for in the model, there is an implicit assumption that growth of these inputs be maintained at about the same rate as in recent years, which was 4 percent in 1986. Failure to provide sufficient quantities of these inputs each year will prevent output from increasing unless substantial efficiency gains in their use occur.

Technological progress is also not explicitly accounted for in the model, but capital is assumed to capture a portion of the technological progress while the policy-related variable PRODCHNG is assumed to capture remaining sources.

Government Policy. The most uncertain aspect of the projection is predicting productivity growth stemming from government policy initiatives. Soviet leaders are, of course, hoping for a dramatic upsurge in farm productivity coming from the intensive technology campaign and recent reform measures. However, boosting farm productivity will not be easy. Long-standing impediments to productivity growth must be overcome before significant progress is possible, including: weak links between the size and quality of harvest and financial rewards for farmworkers; few incentives for managers to reduce production costs; low quality and inappropriate assortment of farm machinery; rural living conditions that are still too stark to encourage younger, skilled workers to stay on the farm; and a rural education system that is inadequate for teaching modern agricultural practices. It is not clear that the programs now in place or planned for agriculture are adequate to the task of substantially raising productivity in the near term.[27] Consequently, three scenarios were constructed by assuming alternative degrees of success for these programs.

Scenarios

The first scenario assumes no change in agricultural policy (that is, PRODCHNG is set equal to 1 for 1988-90, the same value assigned to PRODCHNG for 1986 and 1987). Total factor productivity growth

[27] Goodman, Hughes, and Schroeder, loc. cit.

Table 6
Prospects for Meeting the 12th FYP Goal in Soviet Agriculture [a]

Productivity Assumptions [b]	Five-Year Growth Rate of Output (*percent*)	Odds of Meeting Plan [c]
Scenario 1: No additional productivity growth	**10.7** (8.8-12.6)	Less than 1 in in 100
Scenario 2: Productivity growth sufficient to offset expected losses in employment	**12.4** (10.4-14.3)	1 in 10
Scenario 3: Productivity growth sufficient to sustain the 1968-78 trend (equal to the average rate for 1985-87)	**14.4** (12.3-16.4)	1 in 2

[a] Growth rates were calculated by dividing the average 1986-90 output by the average 1981-85 output (123.19 billion rubles), using actual data for 1986 and 1987. The point estimate (in boldface) assumes average weather, defined here to be the set of weather events associated with the 50th percentile (median) level of output. An 80-percent range estimate, given in parentheses, was derived by incorporating the uncertainties of weather into the analysis. The 80-percent range means there is a 10-percent chance growth could be below the lower limit of the range and a 10-percent chance it could exceed the upper limit of the range. Other assumptions include 5-percent capital growth and −1.5-percent employment growth.
[b] These productivity assumptions were incorporated into the model by adjusting PRODCHNG as follows:

	Scenario 1	Scenario 2	Scenario 3
1988	1.00	1.25	1.70
1989	1.00	1.50	2.10
1990	1.00	1.75	2.50

[c] The goal for Soviet agriculture as stated in the 12th FYP is 14.4 percent over the previous five-year period.

actually declines in this case because the projected decline in employment is not offset by productivity gains and leads to an even greater decline in output growth. Under these conditions, farm output for 1986-90 would increase by only 10.7 percent over the previous five-year period (see table 6) assuming "average" weather conditions. This is considerably less than the 14.4-percent goal, and would clearly represent a failure for Moscow. Even extremely favorable weather would not allow the five-year goal to be met; taking into account the uncertainties of weather, the chances of meeting plan are less than 1 in 100.

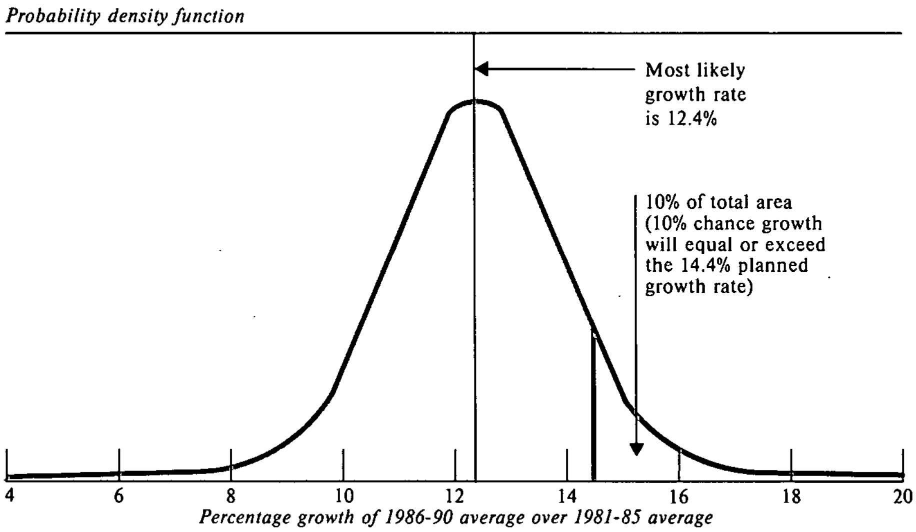
The second scenario assumes Moscow can stimulate productivity enough to offset expected losses in employment (equivalent to a 1.5-percentage-point increase in the growth of total factor productivity). If this can be done, the five-year increase would be 12.4 percent, assuming "average" weather. While an improvement, it still falls short of the FYP goal, and the odds that weather will be favorable enough to meet the FYP goal under these conditions are still only 1 in 10 (see figure 12).

In the third scenario, factor productivity growth was maintained at about 1.4 percent per year, which produces even odds of meeting the plan. At this rate of productivity growth, weather-adjusted output would continue along the 1968-78 trend shown in figure 10. But even if this rate of productivity growth is attained—which may be possible if Gorbachev introduces new programs and policies designed to increase worker efficiency—there is a 50-percent chance that unfavorable weather would erode the positive effect of the productivity gains.

The rate of productivity growth required to ensure that the plan be met for all but the most severe weather outcomes was calculated to be nearly 5 percent per year.[28] Under these conditions, the most likely five-year increase would be 17.7 percent, and odds of falling short of the 14.4-percent goal would be less than 1 in 30. The only historical precedent for sustained productivity growth of this magnitude occurred between 1982 and 1984 as agriculture recovered from the preceding slump period. It is highly unlikely that such productivity gains can be repeated.

[28] For this calculation, the variable PRODCHNG was set equal to 2.0 for 1988, 3.0 for 1989, and 4.0 for 1990.

Figure 12
Projection of Five-Year Growth Rate of Soviet Farm Output Taking Into Account Weather Uncertainties



Note: The projection incorporates actual output results for 1986 and 1987. Assumptions include: (a) 5% growth of capital stock, (b) −1.5% employment growth, and (c) total factor productivity growth sufficient to offset expected losses in employment.

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Conclusions

These model simulations suggest that the Soviets will be able to attain their 1986-90 goal for agricultural output only if the following three conditions prevail:

- At least "average" weather for 1988-90.
- Continued growth of inputs from other sectors at a rate equal to that of recent years, which was 4 percent in 1986, together with timely deliveries.
- Productivity gains not only sufficient to offset losses in the agricultural labor force, but also equivalent to an additional one-percentage-point increase in growth of total factor productivity.

If any of these conditions are not met, the goal will be out of reach. Bad weather could be potentially devastating to output growth, but good weather is equally probable. Even with good weather, however, significant gains in productivity growth will still be needed to meet the FYP.

Appendix A

Development of the Model

The value of agricultural output was modeled as a function of labor, capital, and weather. The starting point for model development is the Cobb-Douglas production function, denoted as:

$$Q = \alpha K^{\beta} L^{1-\beta},$$

where Q is output, K and L are capital and labor inputs, respectively, and α and β are parameters. This basic functional form was modified by converting α into the product of three functions, as follows:

$$\alpha = \alpha_1 \alpha_2(W) \alpha_3(P)$$

The function α_1 is a scale adjustment that reconciles the units of measure used for Q, K, and L. The function $\alpha_2(W)$ contains the weather variables, and thus measures the effects of weather on agricultural output. The function $\alpha_3(P)$ is an adjustment for relative changes in productivity originating directly or indirectly from government programs and policies.

Preliminary Models

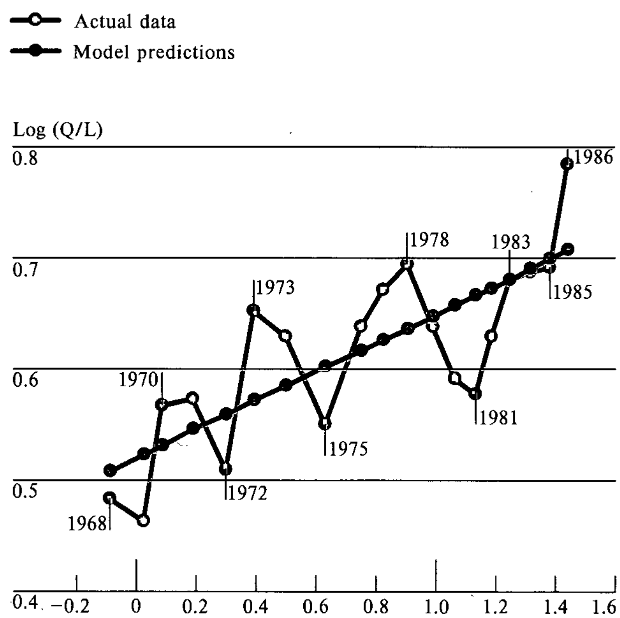
The first step in developing the model was to examine the relationship between capital, labor, and output without accounting for any effects of weather or relative productivity changes. This was done by fitting the intensive form of the function with $\alpha = \alpha_1$:

$$\text{Log}(Q/L) = \text{Log}(\alpha_1) + \beta\ \text{Log}(K/L)^{29}$$

Results indicated that the model was statistically significant (see table A-1). The capital elasticity, β, was estimated to be 0.13. As shown in figure 13, however, substantial variation still remained unexplained.

[29] The intensive form of the Cobb-Douglas production function is derived by dividing both sides of the equation by L, logarithmically transforming both sides, and simplifying.

Figure 13
Model Predictions Using Only Capital and Labor, 1968-86



Q – Farm output in billion 1982 rubles.
L – Labor in billion man-hours.
K – Capital in billion 1973 rubles.

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The second step was to expand the model to include the effects of weather. Preliminary work indicated that this effort would be successful only if measures were taken to isolate the impact of the industrial growth slowdown on agriculture. The simplest approach was to exclude the years 1979-82—the worst of the industrial growth slowdown period—from the model while searching for the relevant weather measures.

Table A-1
Fitting the Model With Capital and Labor Only [a]

Model

$\text{Log}(Q/L) = A_o + \beta \times \log(K/L)$

Parameter Estimates

Variable	Parameter	Parameter Estimate	Standard Error	t for Ho: Parameter = 0	Probability > [t]
Scale adjustment	A_o	0.511432	0.0235466	21.720	0.0001
Capital elasticity	β	0.128111	0.0247510	5.176	0.0001

Analysis of Variance

Source	Degrees of Freedom	Sum of Squares	Mean Square	F value	Probability of a Greater F	$\overline{R}^2$	Durbin-Watson D
Model	1	0.07224344	0.07224344	26.791	0.0001	0.5890	1.517
Error	17	0.04584165	0.00269657				
Corrected total	18	0.11808509					

Note: $\alpha_1 = e^{A_o}$

[a] Parameters were estimated using data on Q, K, and L for 1968-86 (see appendix B).

The objective in selecting weather variables was to choose a few key variables that reflect overall agricultural production, rather than very specific measures that correspond closely to critical growth stages of some particular product, for example, grain. Previous research had shown that gross weather aggregates (weighted according to grain area) such as winter temperature averaged over the six-month period from October to March and spring temperature and precipitation averaged over the four-month period from April to July explained a significant portion of the variation in Soviet grain yields. In the present study, four combinations of temperature and precipitation were tested in addition to temperature and precipitation alone.[30]

[30] The four combinations were:

Temperature×precipitation	=	a measure of hot and wet conditions
Temperature/precipitation	=	a measure of hot and dry conditions
1/(Temperature×precipitation)	=	a measure of cold and dry conditions
Precipitation/temperature	=	a measure of cold and wet conditions

where "×" denotes multiplication and "/" denotes division.

Table A-2
A Preliminary Model Including Weather, Estimated Without 1979-82

Model

$Log(Q/L) = A_0 + \beta \times log(K/L) + A_1 + A_2 \times HOTNDRY + A_3 \times (1/HOTNDRY) + A_4 \times WINTEMP$

Parameter Estimates

Variable	Parameter	Parameter Estimate	Standard Error	t for Ho: Parameter = 0	Probability > [t]
Scale adjustment [a]	A_0	0.507255			
Capital elasticity	β	0.170292	0.016117	10.566	0.0001
Weather variables					
Intercept [a]	A_1	1.643758			
HOTNDRY	A_2	−14.945366	4.7595395	−3.140	0.0105
1/HOTNDRY	A_3	−0.043465	0.0177473	−2.449	0.0343
WINTEMP	A_4	0.028784	0.0080357	3.582	0.0050

Analysis of Variance [a]

Source	Degrees of Freedom	Sum of Squares	Mean Square	F value	Probability of a Greater F	$\overline{R}^2$	Durbin-Watson D
Model	4	0.10621403	0.02655351	29.384	0.0001	0.8902	1.958
Error	10	0.00903678	0.00090368				
Corrected total	14	0.11525081					

Note: $\alpha_1 = e^{A_0}$

$\alpha_2(W) = e^{A_1 + A_2 HOTNDRY + A_3 (1/HOTNDRY) + A_4 WINTEMP}$

[a] The model was initially estimated with only six parameters, including a parameter for the sum of A_0 and A_1. The parameter for the sum of A_0 and A_1 was determined to be 2.15101 with a standard error of 0.58376. A_0 was estimated to be 0.507255 (standard error = 0.02076) by fitting the following model (excluding the years 1979-82):

$$Log(Q/L) = A_0 + \beta log(K/L).$$

A_1 was then determined by solving $A_0 + A_1 = 2.151013$ for A_1.

After some experimentation, two weather measures emerged as key variables. The most important is the ratio of average temperature to cumulative precipitation for the April-July period, named HOTNDRY. Parameters for both HOTNDRY and its reciprocal (1/HOTNDRY) had negative signs, indicating that too much HOTNDRY hurts agriculture and too little HOTNDRY also hurts agriculture. The second weather measure was average winter temperature for the October-March period, named WINTEMP. The parameter for WINTEMP had a positive sign, as expected. Fluctuations in these two variables explained a substantial amount of the year-to-year variation in agricultural output (see table A-2).

Table A-3
The Final Model

Model

$$\text{Log}(Q/L) = A_0 + \beta \times \log(K/L) + A_1 + A_2 \times \text{HOTNDRY} + A_3 \times (1/\text{HOTNDRY}) + A_4 \times \text{WINTEMP} + A_5 \times \text{PRODCHNG}$$

Parameter Estimates

Variable	Parameter	Parameter Estimate	Standard Error	t for Ho: Parameter = 0	Probability > [t]
Scale adjustment [a]	A_0	0.507255			
Capital elasticity	β	0.168433	0.0073280	22.985	0.0001
Weather variables					
Intercept [a]	A_1	1.722217			
HOTNDRY	A_2	−15.692849	2.0572757	−7.628	0.0001
1/HOTNDRY	A_3	−0.045175	0.0076127	−5.934	0.0001
WINTEMP	A_4	0.035548	0.0037783	9.408	0.0001
PRODCHNG	A_5	0.048822	0.00363540	13.430	0.0001

Analysis of Variance [a]

Source	Degrees of Freedom	Sum of Squares	Mean Square	F value	Probability of a Greater F	$\overline{R}^2$	Durbin-Watson D
Model	5	0.11550951	0.02310190	116.605	0.0001	0.9698	2.123
Error	13	0.00257557	0.00019812				
Corrected total	18	0.11808509					

Note:
$\alpha_1 = e^{A_0}$
$\alpha_2(W) = e^{A_1 + A_2 \text{HOTNDRY} + A_3 (1/\text{HOTNDRY}) + A_4 \text{WINTEMP}}$
$\alpha_3(P) = e^{A_5 \text{PRODCHNG}}$

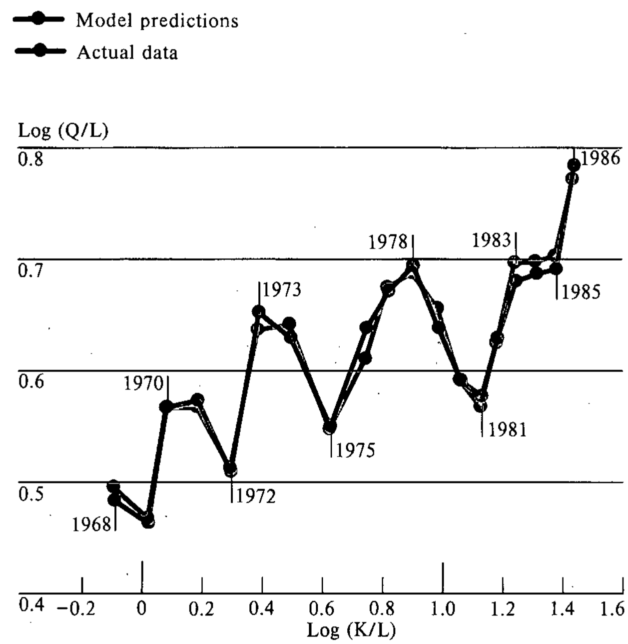
[a] The parameter for the sum of A_0 and A_1 was estimated to be 2.22947 with a standard error of 0.25126. A_1 was estimated using the value for A_0 derived in table A-2.

Total hectarage sown to crops was also considered. However, statistical tests indicated that this variable did almost nothing to reduce the remaining unexplained variation. The year-to-year variation in sown area was perhaps too small to measure the effects of the variable on output in the presence of much stronger influences like weather.

Final Model

The final step in development of the model was to account for changes in productivity that occurred during the 1979-82 period and during 1986-87. For this purpose, the function $\alpha_3(P)$ was created to reflect our subjective estimate of relative changes in productivity owing to government policy actions. The derivation of this function is explained in the main body of this paper. By adding $\alpha_3(P)$ to the model, it was possible to include the years 1979-82 when estimating parameters. The results are shown in table A-3. All parameters were highly significant statistically, and the $\overline{R}^2$ (adjusted for degrees of freedom) was 0.970. The capital elasticity was 0.17, which is slightly higher than the estimate made using only information on capital and labor. Figure 14 illustrates how closely the model predictions correspond to the historical record.

Figure 14
Model Predictions Using Full Model, 1968-86



Q – Farm output in billion 1982 rubles.
L – Labor in billion man-hours.
K – Capital in billion 1973 rubles.

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The final model is:

$$Q = \alpha_1 \alpha_2(W) \alpha_3(P) K^{\beta} L^{1-\beta} \varepsilon,$$

where

α_1 $= e^{A_0}$

$\alpha_2(W)$ $= e^{A_1 + A_2 HOTNDRY + A_3(1/HOTNDRY) + A_4 WINTEMP}$

$\alpha_3(P)$ $= e^{A_5 PRODCHNG}$

β = capital elasticity parameter,

Q = value of agricultural output, excluding farm output used within agriculture (such as feed for livestock and grain for seed), in billions of 1982 rubles,

K = annual capital stock in agriculture at the beginning of the year, excluding livestock, in billions of 1973 rubles,

L = total work-hour employment in agriculture, in billions of hours,

HOTNDRY = ratio of average temperature (degrees centigrade) to cumulative precipitation (millimeters) for April through July, weighted by total sown area,

WINTEMP = average winter temperature (degrees centigrade) for October through March, weighted by area sown to winter wheat,

PRODCHNG = productivity change variable,

$A_0 \ldots A_5$ = statistical parameters, and

ε = stochastic error term.

There are two factors that can influence agricultural output that are not explicitly included in the model—technological progress and material inputs (such as agrochemicals). Technological advances such as higher yielding strains of grain or higher livestock growth rates resulting from genetic improvements would contribute to higher growth. Similarly, increases in grain yields can be attributed in part to increased use of fertilizers and pesticides. Efforts to estimate the model with an additional time-trend variable representing technological progress and variables representing deliveries of agrochemicals to farms were unsuccessful. However, the capital input embodies technological progress to the extent that the value of new machinery and equipment reflects increased efficiency over the old machinery and equipment. "Disembodied" technological progress could also occur as a result of more efficient management and adoption of new farming technologies. To the extent that this disembodied technological progress is an increasing function of time, the capital input—which is also an increasing function of time—acts as a surrogate, or proxy, for it. For the same reason, capital also serves as a proxy for material inputs.

Testing for the Effects of the Industrial Growth Slowdown

The model was used to conduct a statistical test to determine if the industrial growth slowdown during 1979-82 had a detrimental effect on agricultural performance. The final model presented in table A-3 was reestimated after replacing the function $\alpha_3(P)$ by a dummy variable (DUM) consisting of 1's for the years 1979-82 and 0's for all other years.[31] A parameter value for DUM that is not significantly greater than zero would suggest that nonweather factors other than capital and labor had little to do with the poor agricultural performance during this time. As shown in table A-4, the parameter for DUM was highly significant statistically (that is, the probability of a greater t-value was less than 0.0001 under the null hypothesis that the parameter's true value is zero), indicating that nonweather factors other than capital and labor were indeed responsible for the associated growth slowdown in agriculture during 1979-82.

[31] A dummy variable is a time-series sequence of 1's and 0's. Use of the dummy variable in hypothesis testing is equivalent to performing an analysis of variance and testing for significant group effects—where the two time periods represent two groups—while simultaneously accounting for variation between the two groups that is due to differences in capital and labor inputs and weather.

Table A-4
Testing for Effects of the Industrial Growth Slowdown

Model

$$\text{Log}(Q/L) = A_0 + B \times \log(K/L) + A_1 + A_2 \times \text{HOTNDRY} + A_3 \times (1/\text{HOTNDRY}) + A_4 \times \text{WINTEMP} + A_5 \times \text{DUM}$$

Parameter Estimates

Variable	Parameter	Parameter Estimate	Standard Error	t for Ho: Parameter = 0	Probability > [t]
Scale adjustment [a]	A_0	0.507255			
Capital elasticity	β	0.168434	0.0160888	10.469	0.0001
Weather variables					
Intercept [a]	A_1	1.607773			
HOTNDRY	A_2	−14.646667	4.41654502	−3.316	0.0056
1/HOTNDRY	A_3	−0.042382	0.01635564	−2.591	0.0224
WINTEMP	A_4	0.026284	0.00769052	3.418	0.0046
Dummy variable for 1979-82	A_5	**−0.104958**	**0.01952918**	**−5.374**	**0.0001**

Analysis of Variance [a]

Source	Degrees of Freedom	Sum of Squares	Mean Square	F value	Probability of a Greater F	$\overline{R}^2$	Durbin-Watson D
Model	5	0.10619527	0.02123905	23.222	0.0001	0.8606	1.552
Error	13	0.01188982	0.00091460				
Corrected total	18	0.11808509					

[a] The parameter for the sum of A_0 and A_1 was estimated to be 2.11503 with a standard error of 0.53949. A_1 was estimated using the value for A_0 derived in table A-2.

Comparison of Preliminary and Final Models

To perform simulations with the model, it is important that the parameters be measured without significant bias. One source of bias common to econometric models is "multicolinearity." Multicolinearity is a sample problem for which the sample does not provide "rich" enough information on the explanatory variables (such as HOTNDRY, WINTEMP, K, and L) to prevent one variable from inordinately influencing the parameter estimate of another variable. In other words, multicolinearity is a problem when the explanatory variables are not sufficiently independent to meet the requirements of the model.

Table A-5
Comparison of Preliminary and Final Models

Billion 1982 rubles

	Farm Output			Weather-Adjusted Farm Output		
	Actual Data	Predicted		Final Model	Preliminary Model	Difference [a]
		Final Model	Preliminary Model			
1968	105.061	106.393	106.242	105.757	105.901	−0.144
1969	100.303	100.732	101.856	105.939	104.788	1.151
1970	112.535	112.464	111.797	108.749	109.428	−0.679
1971	111.388	110.707	110.350	109.685	110.094	−0.409
1972	104.660	104.986	105.826	110.766	109.962	0.804
1973	121.807	119.841	118.830	115.747	116.833	−1.086
1974	119.629	121.073	120.394	115.221	115.994	−0.773
1975	109.410	109.094	108.309	118.221	119.233	−1.012
1976	118.060	114.802	115.811	122.192	121.312	0.880
1977	122.829	123.288	123.185	120.685	120.986	−0.301
1978	126.605	125.758	125.201	124.472	125.252	−0.780
1979	118.927	120.991	126.886	116.730	117.106	−0.376
1980	113.740	113.732	125.816	114.749	114.608	0.141
1981	112.500	111.332	127.930	112.040	113.135	−1.095
1982	120.788	120.174	138.134	114.578	115.672	−1.094
1983	128.638	130.706	136.083	126.500	127.892	−1.392
1984	128.046	129.277	129.442	133.780	133.955	−0.175
1985	125.992	127.435	129.114	132.537	131.169	1.368
1986	136.287	134.448	128.699	142.117	141.792	0.325
1987	132.032	131.575	127.060	139.566	138.048	1.518

[a] Final model predictions minus preliminary model predictions.

In the final model presented above, there is potential for multicolinearity between the functions $\alpha_2(W)$ and $\alpha_3(P)$. One way to determine if multicolinearity is a problem is to compare parameter estimates of the full model with parameter estimates for a restricted model. Such a comparison can be made here by contrasting the preliminary model in table A-2, which excludes $\alpha_3(P)$, with the final model in table A-3, which includes $\alpha_3(P)$. Parameter estimates for the two models differ very little. Furthermore, there is little difference in model predictions for years other than 1979-82 and 1986-87, as shown in table A-5. In the final model, the function $\alpha_3(P)$ adjusts for the additional nonweather factors influencing farm output during 1979-82 and 1986-87 and thus produces better predictions for those years. Most important, trends in the weather-adjusted farm output series created using the two models are almost identical (see table A-5), even for 1979-82 and 1986-87. These results indicate strongly that, if multicolinearity between weather and the productivity change variable exists, it is not biasing parameter estimates for the weather variables to any significant extent.

Appendix B

Data

Parameters of the model were estimated using data from 1968 through 1986. The period was not extended to 1987, because reliable employment data for 1987 were not available at the time of the study, and only preliminary data on farm output were available.

Agricultural Capital Stock

The Soviet definition of fixed capital includes the undepreciated value of buildings, structures, conveying equipment, machinery and equipment (including measurement and control instruments, laboratory equipment, and computer hardware), vehicles, tools, and productive and draft livestock of basic herds (but excluding young livestock, livestock allocated for fattening, and some minor categories such as poultry, rabbits, and fur-bearing animals). Fixed capital is broken down into productive and nonproductive capital. Productive capital is that used directly in the production process. Nonproductive capital includes capital in the housing and municipal services sector and in organizations and institutions of public health, education, science, culture, art, credit institutions, and administrative organs.

In fitting the model, nonproductive fixed capital was excluded, as was productive livestock. The data used are shown in table B-1.

Table B-1 *Billions of rubles*
Productive Fixed Capital Stock and Capital Investment in Soviet Agriculture

	Beginning-of-Year Capital Stock (in comparable 1973 prices)		Capital Investment (in comparable 1984 prices) [c]
	Including Livestock [a]	Excluding Livestock [b]	
1965	72	49	10.600
1966	77	54	11.308
1967	82	58	12.069
1968	87	63	13.466
1969	93	69	14.029
1970	98	74	16.000
1971	106	82	18.410
1972	116	91	20.151
1973	126	101	22.249
1974	140	113	24.179
1975	154	127	26.100
1976	167	141	27.190
1977	180	153	27.910
1978	194	167	28.895
1979	209	181	29.519
1980	223	195	29.800
1981	238	210	30.500
1982	254	225	30.925
1983	272	242	31.978
1984	288	258	31.000
1985	303	272	31.500
1986	316	286	33.500
1987	330	300	

[a] *Narodnoye khozyaystvo SSSR za 70 let.*, Central Statistical Administration, Moscow, 1987, p. 100, and other years.
[b] Based on indexes published in *Narodnoye khozyaystvo SSSR za 70 let.*, Central Statistical Administration, Moscow, 1987, p. 101, and other years.
[c] *Narodnoye khozyaystvo SSSR za 70 let.*, Central Statistical Administration, Moscow, 1987, p. 276, and other years.

Employment in Agriculture

Agricultural workers fall into four basic categories: workers and employees on state farms; collective farmers; persons engaged in private farming; and temporary workers recruited from nonfarm industries, the military, and schools to help during peak agricultural periods, primarily the harvest season. The Soviets report average annual employment statistics for state and collective farms as well as the number of

Table B-2
Employment in Socialized Agriculture

	Employment (*million workers*)				Man-Days per Month		Hours Worked per Year per Worker		Total Hours Worked (*millions*)			
	State Farms (1)	Collective Farms (2)	Recruits (3)	Total (4)	State Farms (5)	Collective Farms (6)	State Farms (7)	Collective Farms (8)	State Farms (9)	Collective Farms (10)	Recruits (11)	Total (12)
1968	8.548	15.782	0.5				1,907	1,580	16,299	24,934	790	42,023
1969	8.725	15.010	0.6				1,890	1,585	16,490	23,798	951	41,240
1970	8.833	14.667	0.6	24.1	22.8	19.2	1,915	1,613	16,917	23,655	968	41,540
1971	9.122	13.478	0.7	23.3			1,924	1,630	17,547	21,973	1,141	40,661
1972	9.244	13.456	0.8	23.5			1,924	1,651	17,782	22,210	1,320	41,313
1973	9.462	13.238	0.9	23.6			1,932	1,669	18,281	22,092	1,502	41,874
1974	9.656	13.044	0.9	23.6			1,932	1,694	18,655	22,097	1,525	42,277
1975	9.787	12.713	1.0	23.5	23.1	20.3	1,940	1,705	18,991	21,678	1,705	42,374
1976	9.970	12.430	1.1	23.5	23.2	20.6	1,949	1,730	19,430	21,509	1,903	42,842
1977	10.180	12.020	1.1	23.3	23.1	20.7	1,940	1,739	19,753	20,900	1,913	42,566
1978	10.387	11.613	1.3	23.3	23.1	21.0	1,940	1,764	20,155	20,485	2,293	42,933
1979	10.481	11.319	1.3	23.1	23.0	21.2	1,932	1,781	20,249	20,157	2,315	42,721
1980	10.693	10.907	1.3	22.9	23.1	21.4	1,940	1,798	20,749	19,606	2,337	42,692
1981	10.817	10.483	1.4	22.7	23.2	21.6	1,949	1,814	21,080	19,020	2,540	42,641
1982	10.978	10.522	1.4	22.9	23.2	21.8	1,949	1,831	21,394	19,268	2,564	43,225
1983	11.098	10.402	1.5	23.0	23.2	22.2	1,949	1,865	21,628	19,398	2,797	43,823
1984	11.102	10.198	1.5	22.8	23.2	22.3	1,949	1,873	21,636	19,103	2,810	43,548
1985	11.095	9.905	1.4	22.4	23.1	22.4	1,940	1,882	21,529	18,637	2,634	42,800
1986	10.968	9.632	1.4	22.0	23.1	22.4	1,940	1,882	21,282	18,124	2,634	42,040

Sources:
Column (1): *Narodnoye khozyaystvo SSSR za 70 let.*, Central Statistical Administration, Moscow, 1987, p. 86, and other years.
Column (2): column (4) minus column (1) minus column (3). Values for 1968-69 were taken from Stephen Rapawy, *Civilian Employment in the USSR 1950 to 1983*, CIR Staff Paper No. 10, US Department of Commerce, Bureau of the Census, August 1985, p. 31.
Columns (3) and (4): *Narodnoye khozyaystvo SSSR za 70 let.*, Central Statistical Administration, Moscow, 1987, p. 300, and other years.
Column (5): *Narodnoye khozyaystvo SSSR za 70 let.*, Central Statistical Administration, Moscow, 1987, p. 292, and other years.
Column (6): *Narodnoye khozyaystvo SSSR za 70 let.*, Central Statistical Administration, Moscow, 1987, p. 288, and other years.
Column (7): column (5) multiplied by 12 months per year and seven hours per day. Values for 1968-69 and 1971-74 were derived from data reported by Stephen Rapawy, *Civilian Employment in the USSR 1950 to 1983*, CIR Staff Paper No. 10, US Department of Commerce, Bureau of the Census, August 1985, p. 29.
Column (8): column (6) multiplied by 12 months per year and seven hours per day. Values for 1968-69 and 1971-74 were derived from data reported by Stephen Rapawy, *Civilian Employment in the USSR 1950 to 1983*, CIR Staff Paper No. 10, US Department of Commerce, Bureau of the Census, August 1985, p. 31.
Column (9): column (1) multiplied by column (7).
Column (10): column (2) multiplied by column (8).
Column (11): column (3) multiplied by column (8).
Column (12): column (9) plus column (10) plus column (11).

Table B-3
Employment in Private Agriculture and Total Employment

	Private Agriculture					Total Hours Worked in Agriculture (*millions*)
	Number of Productive Livestock (*end of year, millions*)			Sown Area (*million hectares*)	Total Hours Worked (*millions*)	
	Cattle (1)	Swine (2)	Sheep and Goats (3)	(4)	(5)	(6)
1968	27.3	12.8	34.4	6.77	22,771	64,794
1969	25.0	13.8	31.7	6.78	21,868	63,108
1970	25.0	16.6	33.2	6.73	22,292	63,832
1971	24.9	15.9	32.7	6.68	22,089	62,750
1972	24.7	13.3	32.3	6.67	21,551	62,864
1973	24.6	13.6	32.1	6.64	21,525	63,399
1974	24.5	13.7	32.0	6.64	21,489	63,766
1975	23.5	12.2	29.4	6.64	20,716	63,090
1976	22.8	11.8	28.8	5.93	19,519	62,361
1977	23.3	14.8	29.4	5.93	20,212	62,779
1978	23.1	14.8	29.2	6.05	20,277	63,211
1979	23.1	14.8	25.3	6.05	20,109	62,830
1980	23.0	14.0	30.2	6.16	20,280	62,972
1981	23.4	14.2	30.7	6.15	20,488	63,129
1982	24.2	15.8	31.9	6.16	21,139	64,365
1983	24.6	15.6	33.2	6.16	21,331	65,153
1984	24.0	14.1	32.5	6.17	20,824	64,372
1985	24.1	13.9	33.1	5.70	20,313	63,114
1986	23.7	13.6	33.4	5.72	20,135	62,175

Sources:
Columns (1), (2), and (3): *Narodnoye khozyaystvo SSSR za 70 let.*, Central Statistical Administration, Moscow, 1987, p. 253, and other years.
Column (4): *Narodnoye khozyaystvo SSSR za 70 let.*, Central Statistical Administration, Moscow, 1987, p. 225, and other years.
Column (5): derived from columns (1), (2), and (3); see text.
Column (6): column (5) plus column (12) from table B-2.

workers involved in temporary seasonal activity. From this information, an estimate of total work hours in socialized agriculture can be made (see table B-2).

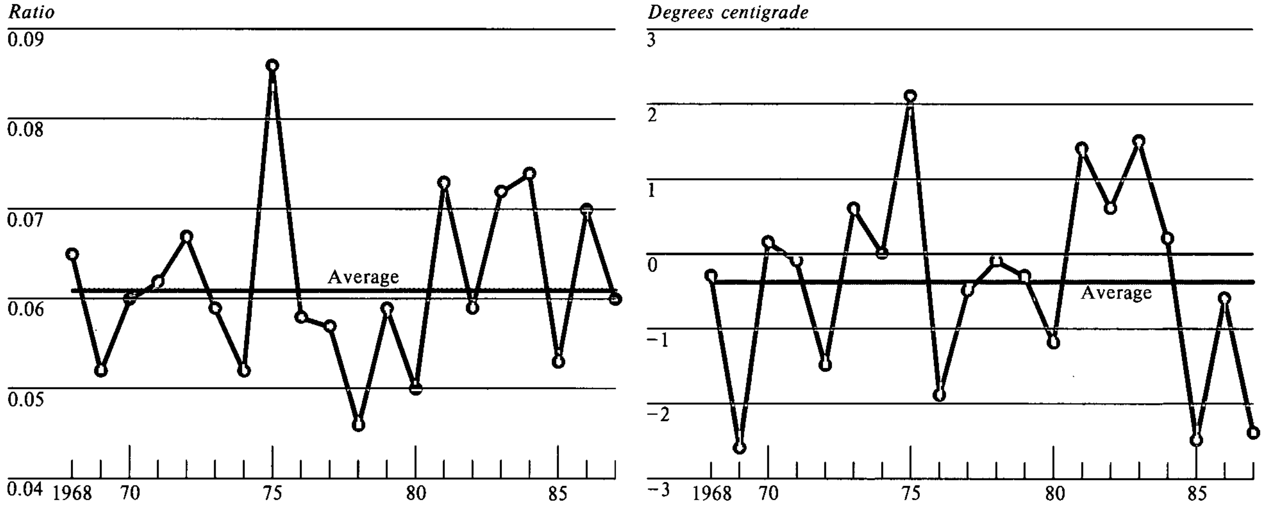
Although the Soviets report statistics on the number of workers in private agriculture, the model requires data on employment in hours worked, which they do not report. Using a method developed by the US Department of Commerce, Center for International Research, an estimate of private employment in hours worked can be derived from data on the number of livestock on private farms and the area allocated for private plots. (see table B-3).[32] This is done using labor

[32] See Stephen Rapawy, *Estimates and Projections of the Labor Force and Civilian Employment in the USSR 1950 to 1990*, Foreign Economic Report No. 10, US Department of Commerce, Bureau of Economic Analysis, September 1976, p. 43.

Figure 15
Weather Data Used in Model, 1968-87

Ratio of Temperature to Precipitation April-July (HOTNDRY) — *Ratio*

Average Winter Temperature October-March (WINTEMP) — *Degrees centigrade*



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coefficients obtained from the Soviet literature, as follows:

Activity	Input Required (*man-days/per unit*)
Cultivation of one sown hectare	166.0
Tending one head of cattle	54.2
Tending one pig	20.6
Tending one sheep or goat	5.6

The total man-days for animal husbandry are increased by 10 percent to allow for labor involved in tending poultry, horses, and rabbits, which otherwise would not be included. Man-days are converted to total hours by multiplying by seven hours per day, the same daily work rate assigned to state and collective farms.

Weather

Detailed meteorological data from the USSR are available through the World Meteorological Organization. As a member, the USSR shares such information with foreign countries. These data are part of a worldwide standardized system that attempts to ensure consistent measures of weather parameters from year to year. Precipitation and temperature data are available for approximately 1,000 stations located throughout the grain-growing portion of the USSR.[33] The data is processed and corrective measured applied

[33] Summaries of the data for 27 crop regions are reported in *Climate Impact Assessment, Foreign Countries*, published by the National Oceanic and Atmospheric Administration (NOAA). For the present study, eight additional crop regions were created, predominantly in Siberia and Kazakhstan.

to overcome reporting errors and omissions. Although the original data set extends to the mid-1940s, the "corrected" data set begins in 1969. It was possible to use the "uncorrected" weather data for 1968 and thus extend the data set an additional year, but attempts to include years before 1968 in the model were unsuccessful.[34]

These data were used to calculate monthly precipitation and average monthly temperature for the agricultural area of the USSR. Two weighting schemes were used to aggregate the data. Precipitation and temperature for the variable HOTNDRY were weighted according to the area sown to all crops, whereas temperature data for WINTEMP were weighted according to area sown to winter wheat.[35] HOTNDRY is the ratio of average temperature to cumulative precipitation for April through July. WINTEMP is the average temperature for October through March.

The data and summary statistics for HOTNDRY and WINTEMP are shown in table B-4 (also see figure 15). The mean and standard deviation were used to generate a probability distribution for each variable in order to conduct the stochastic simulation exercise. HOTNDRY and WINTEMP are positively correlated; the Pearson correlation coefficient measured 0.595 (with a standard error of 0.139). That is, when WINTEMP is high, HOTNDRY is often—but not always—high as well. Consequently, simulated values

[34] The two weather data sets also had different area definitions, and so it was necessary to link the two series. This was done for 1968 data as follows:

$$\text{Value for 1968} = \frac{\text{"corrected" value for 1969}}{\text{"uncorrected" value for 1969}} \times \text{"uncorrected" value for 1968}$$

[35] The calculation was made as follows:

$$\sum_{i=1}^{35} \left[\begin{array}{c}\text{Share of total}\\ \text{area in area i}\end{array}\right] \times \left[\begin{array}{c}\text{Weather data}\\ \text{for area i}\end{array}\right] = \text{Weighted weather data}$$

Table B-4
Weather Data

	HOTNDRY	WINTEMP
Data		
1968	0.065680	−0.03
1969	0.052343	−2.60
1970	0.059621	0.15
1971	0.062416	−0.10
1972	0.066987	−1.50
1973	0.059346	0.60
1974	0.052102	0.00
1975	0.085941	2.10
1976	0.058007	−1.90
1977	0.056889	−0.50
1978	0.046413	−0.10
1979	0.059482	−0.30
1980	0.049892	−1.20
1981	0.073477	1.40
1982	0.058703	0.60
1983	0.072209	1.50
1984	0.074187	0.20
1985	0.053265	−2.50
1986	0.069834	−0.60
1987	0.059304	−2.40
Percentiles [a]		
99%	0.085942	2.1
90%	0.074187	1.5
75%	0.069834	0.6
50% (median)	0.059483	−0.1
25%	0.053266	−1.5
10%	0.049892	−2.5
1%	0.046414	−2.6
Mean	**0.061613**	**−0.376**
Standard deviation	**0.0099342**	**1.36426**

Note: Neither of these distributions were significantly different from the normal distribution. Data for 1968 were excluded from calculations of summary statistics.

[a] A percentile represents the probability that a value equal to or less than the tabled value would be expected to occur, based on the 19 observations in the original frequency distribution. For example, a value of HOTNDRY equal to or less than 0.053266 (the value for the 25th percentile) would be expected to occur about once every four years, on average.

Table B-5
Derivation of Value-Added, Weather-Adjusted Farm Output

	Weather-Adjusted Farm Output		Gross Weather-Adjusted Output Including Current Purchases (*billion rubles*)	Current Purchases (*billion rubles*)	Value-Added Weather-Adjusted Output	
	Actual (*billion rubles*)	Index			Actual (*billion rubles*)	Index
	(1)	(2)	(3)	(4)	(5)	(6)
1968	105.757	0.923	120.361	20.1494	100.211	1.000
1969	105.939	0.924	120.568	20.9693	99.599	0.993
1970	108.749	0.949	123.766	21.6942	102.072	1.018
1971	109.685	0.957	124.831	22.7634	102.068	1.018
1972	110.766	0.966	126.062	24.2611	101.801	1.015
1973	115.747	1.010	131.730	25.9391	105.791	1.055
1974	115.221	1.005	131.132	27.5947	103.537	1.033
1975	118.221	1.031	134.546	29.2831	105.262	1.050
1976	122.192	1.066	139.066	28.3749	110.691	1.104
1977	120.685	1.053	137.350	31.1685	106.182	1.059
1978	124.472	1.086	141.661	31.6678	109.993	1.097
1979	116.730	1.018	132.850	32.1303	100.719	1.005
1980	114.749	1.001	130.595	33.1553	97.440	0.972
1981	112.040	0.977	127.511	34.0618	93.450	0.932
1982	114.578	1.000	130.400	35.2400	95.160	0.949
1983	126.500	1.104	143.968	37.8364	106.132	1.059
1984	133.780	1.167	152.254	39.1360	113.118	1.128
1985	132.537	1.156	150.839	41.0018	109.838	1.096
1986	142.117	1.240	161.742	42.7994	118.943	1.186
1987	139.566	1.218	158.839	43.6574	115.182	1.149

Sources:
Column (1): weather-adjusted output series from table 3.
Column (2): column (1) divided by 114.578, the value of weather-adjusted output for 1982.
Column (3): column (2) multiplied by 130.4 billion rubles, which is the 1982 gross value of farm output estimated by extending the 1972 input-output table forward to 1982. It represents complete coverage of gross output minus interfarm use, as opposed to the net farm output measure used in this study, which is based on a sample.
Column (4): current purchases.
Column (5): column (3) minus column (4).
Column (6): column (5) divided by 100.211, the value of value-added weather-adjusted output for 1968.

for HOTNDRY and WINTEMP were created such that this correlation was preserved; the Pearson correlation coefficient of simulated values was 0.585.

Farm Output

The Soviet measure of gross agricultural output is inadequate for modeling purposes because no adjustment is made for intra-agricultural use of farm products (such as seed and animal feed) and because Soviet gross output statistics include a large element of waste. The measure of farm output used in this study—net farm output—is the sum of livestock production and crop production, minus seed, feed and waste, valued in average 1982 realized prices. Derivation of the series has previously been described in detail.[36] Net farm output is based on a sample of 28 individual crops, 10 livestock products, and four items of livestock inventory change. These 42 products account for nearly 95 percent of total farm output net of intrafarm use of crops.

[36] See Barbara Severin and Margaret Hughes, "Part III. An Index of Agricultural Production in the USSR," in *USSR: Measures of Economic Growth and Development, 1950-80*, Joint Economic Committee, Congress of the United States, December 1982, pp. 245-316.

Value-Added Farm Output

Total factor productivity was calculated using value-added farm output. Value-added farm output excludes not only production for intrafarm use, but also the value of materials and services purchased by agriculture on current account from nonagricultural sectors (current purchases). The time series for current purchases is based on 10 indexes of material inputs.[37] Weather-adjusted farm output is converted to a value-added measure according to the method presented in table B-5.

[37] See John Pitzer, "Part I. Gross National Product of the USSR, 1950-80," in *USSR: Measures of Economic Growth and Development, 1950-80*, Joint Economic Committee, Congress of the United States, December 1982, pp. 88-91.