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State-Directed Diffusion of Technology: The Mechanization of Cotton Harvesting in Soviet Central Asia

RICHARD POMFRET

When Soviet central planners began to mechanize the cotton harvest in earnest in 1958, they expected more rapid diffusion than the market-driven process that had begun in the United States a decade earlier. But despite high output of cotton-picking machines, the share of the crop harvested mechanically grew more slowly than in the United States. The factor proportions in Central Asia did not justify mechanization: although planners could enforce introduction of the new technology, investment in cotton-harvesting machines was largely a waste of resources. The costs of premature introduction are estimated at over \$1 billion in 1960s prices.

The relative merits of market-based and state-directed approaches is a recurring theme in the literature on the diffusion of new technology. This article addresses the issue in the context of technology embodied in a machine, the mechanical cotton harvester. It contrasts the market-driven diffusion process in the United States with state-directed diffusion in the Soviet Union.

In market economies the speed of diffusion depends on the technical characteristics of the machine (including improvements and variations on the basic design), relative factor prices, and, in some cases, scale effects due to indivisibilities or complementarities.¹ Competition can be effective in prompting continuous improvements, inducing institutional innovation to overcome obstacles to diffusion, and filling missing markets. Competition may, however, lead to inefficient use of resources, pursuing too many tech-

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¹ On the importance of technical improvements (the D in R&D) and of informational gaps and interdependencies, see Rosenberg, *Inside the Black Box*. The classic account of the S-shaped diffusion path of new technology is Griliches, "Hybrid Corn." The threshold model introduces indivisibilities, and combined with the size distribution of potential adopters generates an S-shaped diffusion path; for application to the diffusion of mechanical reapers, see David, "Mechanization"; and Pomfret, "Mechanization." On tractor adoption, see Ankli, "Horses"; and Lew, "Diffusion." The threshold model has been criticized by Olmstead, "Mechanization" and "Diffusion"; and by Olmstead and Rohde, "Beyond the Threshold," who also emphasize the uncertainty inherent in the market and the nature of credit institutions and farm organization. On the diffusion of tractors among U.S. cotton farmers see Musoke, "Mechanizing"; and Whatley, "History."

nological variants or producing too many models in suboptimally scaled factories. Public policy may be superior to market forces in providing such public goods as technical standards and secure intellectual property rights. If indivisibilities matter, the state can encourage consolidation and cooperation among both producers and consumers of the capital goods that embody the new technology. In the Soviet Union the state played all of these roles, consolidating both production of the capital equipment and potential adopters of the new technology.

Technical problems in the development of economical cotton-harvesting machines were overcome in the 1930s and 1940s. The machine-picked share of the cotton harvest in the United States increased in a classic S-shaped diffusion pattern between 1949 and the late 1960s, starting in high-wage California and occurring later in low-wage southeastern states, especially the less geographically suited coastal areas of South Carolina.² By the end of the 1960s, 96 percent of the U.S. cotton crop was harvested mechanically.³ Mechanization of the Soviet cotton harvest began in earnest about a decade later, but with the government giving high priority to the process after 1958 it was expected that centrally planned diffusion would be rapid.⁴

The outcome was, however, not a steep diffusion path to more or less complete mechanization. Diffusion was slower in the Soviet Union than in the United States, and even reversed itself after 1981 (Figure 1). Three-quarters of the cotton crop was mechanically harvested by 1959 in California, by 1962 in Texas, by 1965 in Mississippi, and by 1968 in South Carolina, but no major cotton-producing Soviet republic ever reached this share.⁵ Despite rapid build-up of machine production in the early 1960s and an increasing share of machine-harvested cotton in the 1960s and 1970s, machine use was below capacity from the start; and by the 1980s, the share of machine-picked cotton was declining in the Soviet Union.

How to explain this phenomenon? A picture is often painted of bungling politicians and planners failing to maintain production of mechanical harvesters and complementary inputs, or failing to appreciate the importance of model variations to suit differing conditions or of repair and maintenance services. Other authors see a plot to delay diffusion in order to keep Central

² See Musoke and Olmstead, "Rise"; and Grove, "Farmers."

³ Whatley, "New Estimates," p. 199.

⁴ Priority was given to replacement of back-breaking work by modern machines in part because it provided good publicity when, at the peak of Soviet prestige in the Third World, Soviet Central Asia was held up as a model, contrasted to southern neighbors both in the satisfaction of basic needs and in economic dynamism. Western economists also accepted this image; see Nove and Newth, *Soviet Middle East*; Conolly, *Beyond the Urals*, pp. 55–241; and Wilber, *Soviet Model*.

⁵ The U.S. data are from Musoke and Olmstead, "Rise," pp. 405–06. The minor Soviet exception was Kazakhstan, where the reported share of the harvest picked by machine exceeded 75 percent in 1985 and 1988, although these spikes look implausible in the long-term context (Table 6). Less than 5 percent of Soviet land under cotton in the late 1980s was in Kazakhstan (Table 2).

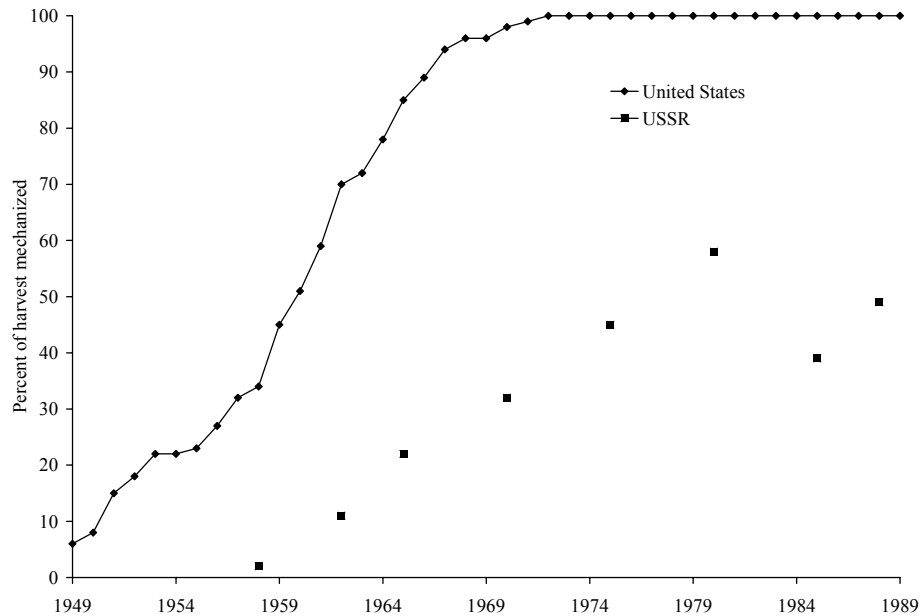


FIGURE 1
THE MECHANIZATION OF COTTON-HARVESTING IN THE UNITED STATES AND THE
USSR, 1949–1988

Sources: See the text.

Asian peasants on the land and prevent the social disruption associated with rural–urban migration. On these views, it is not the state-directed approach itself that was at fault, but rather poor implementation by planners. I, however, shall argue that the “failure” of mechanization was due to resistance by cotton growers. The central authorities were pushing for too-rapid diffusion, and by the 1980s they failed to maintain even the diffusion levels achieved in the 1960s and 1970s due to resistance at the level of the *kolkhoz* (collective farm). Planners saw the benefits of mechanization as self-evident, ignoring its real and opportunity costs, as well as its distributional impact.

How do we know that the intended diffusion was premature? One indication is the phenomenon of idle machinery during the Soviet period. Even when machines were available, *kolkhoz* managers chose to leave them idle and have the cotton picked by hand. Despite the low valuation by the users, real resources went into the manufacture of the machines. Another sign that diffusion had been too rapid is that when the post-Soviet successor states shifted to greater market orientation in the 1990s, demechanization continued apace.⁶ Although reliable data on the share of machine-picked cotton in

⁶ Of course, many things changed after the collapse of central planning which may have affected the demand for machinery, but the fundamental factor proportions had not. Characterizing the successor

post-Soviet Central Asia are hard to come by, anecdotal evidence suggests that hand-picking became even more prevalent in the 1990s.⁷ By the turn of this century, machine production had collapsed.

I will first set the scene by providing technical background material and discussing the role of political leaders and central planners at the innovation stage, where some of the Soviet Union's latecomer advantage was dissipated by political intervention. A following section discusses arguments that neo-colonial political leaders hampered the diffusion process. I go on to posit an alternative hypothesis, that resistance to mechanization was at the *kolkhoz* level where, for the majority of adult male members, the costs of mechanization exceeded the benefits; I assess the outcome in terms of social costs and benefits, and argue that although the interests of *kolkhoz* managers were determined within the framework of collectivized agriculture, their actions reflected the economic unsuitability of mechanical harvesting in labor-abundant Soviet Central Asia. A lower-bound valuation of the resources wasted in premature diffusion is \$1 billion at 1960 prices. The final section draws some conclusions, emphasizing that while public intervention can accelerate the pace of technological diffusion, this may not be a desirable outcome.

POLITICS, PLANNING, AND INNOVATION

Cotton harvesting was one of the slowest major agricultural processes to undergo mechanization, even in high-wage countries. Although the first patent had been taken out in 1850 and cotton mechanization was henceforth always "just around the corner," general adoption of mechanical cotton pickers began in California only in 1949, and in the southeastern United States in the early 1960s.⁸ The problems were both economic and technical.

economies as more market-oriented is not to deny that the cotton sector remains highly distorted in the successor states, most strikingly with state monopsonies in Uzbekistan and Turkmenistan. Nevertheless, the end of central planning did lead to changes. Especially significant in the present context is the disconnection of the machinery industry from the cotton growers, who are now less pressured to accept delivery of new machines. In the planned economy, the level of compulsion in the labor market may have reduced the incentive to economize on labor, but the shift to market-based labor allocation should have reversed this bias. Note that in analyzing factor proportions input markets are of greater significance than the lack of competition in the output market, assuming that decision-makers place some weight on cost reduction.

⁷ The World Bank's poverty assessment of Tajikistan (20285-TJ, 29 June 2000, p. 64) mentions that "cotton harvesting is almost exclusively manual." Andrew Apostolou, an Oxford University historian, refers to the Uzbekistan 1999 cotton crop, "an incredible 96.5 percent of which was collected by hand" ("Uzbek Model").

⁸ The quotation is from Hon, "Rust," p. 384. Strippers, which snapped cotton bolls off at the top of the stalk and failed to distinguish ripe bolls from unripe ones and trash, were used in Texas and Oklahoma after 1926, but were less efficient than the later cotton pickers which picked only ripened bolls. Production of cotton pickers appears to have begun in 1946, when 107 machines were produced; by 1951, over 3,500 machines were being produced annually in the United States (Street, *New Revolution*, p. 133).

Despite the labor-intensity of hand-picking, the economic incentive to introduce expensive harvesting machines was insufficient, even in high-wage California, before the late 1940s. Mechanized picking also impaired the quantity and quality of cotton harvested. Machines missed some plants and knocked the bolls off others; they also compressed the soil, destroying nutrients and reducing future yields. Machine-harvested cotton was moister and contained more impurities than hand-picked cotton, and was therefore harder to process, which led to problems with the processing equipment. Moreover, mechanization presupposed costly complementary adjustments, including the development of simultaneously ripening strains, the straightening of furrows and planing of fields, the application of herbicides and defoliants, and the precise timing of the harvest before rainfall. Failure to provide for any of these would reduce drastically the efficacy of the equipment.

Ever since the Russian conquest of Central Asia in the 1860s, the central government had promoted cotton production through technological borrowing and heavy investment.⁹ In the 1870s the first Russian governor-general sent two specialists to Texas to obtain new seed varieties. As with the mechanical harvester, U.S. varieties required selection and adaptation to the climatic and topographical conditions of Central Asia, for the purposes of which an experimental station was established in Tashkent. Railway construction facilitated transport to the textile mills of Russia. Irrigation projects increased the land available for cotton sowing, and here again the Soviet government drew on foreign expertise.¹⁰ By 1940 cotton output was triple that of 1913, and 1980 output was four-and-a-half times that of 1940 (Table 1). Hectares sown with cotton increased correspondingly (Table 2). Almost all of the cotton was grown in Central Asia, with over half of the harvest from the Uzbek republic and most of the remainder from the neighboring Tajik and Turkmen republics.¹¹

Soviet policymakers closely followed the development of practical cotton harvesting machinery in the United States. They purchased two of the ten machines built by the Rust Brothers in the United States in 1936, and invited the inventors to the Soviet Union in the same year. The first mass-produced Soviet cotton harvester, a vertical-spindle machine called the SkhM-48, appeared in 1949.

⁹ Before the 1860s Central Asia supplied less than 10 percent of Russia's cotton, but by the 1930s the Soviet Union was self-sufficient in cotton, and it became an exporter in the 1950s.

¹⁰ Arthur Davis, a well-known U.S. irrigation engineer, surveyed the feasibility of irrigating the Goldnaya Steppe in 1913. Fifteen years later his proposal was accepted, and in June 1929 Davis went to the Soviet Union, where he was given engineering responsibility for the Central Asian irrigation program. Other U.S., Japanese, and Korean technicians worked on the Central Asian cotton economy, although most left in 1931; see Sutton, *Western Technology*, pp. 32–43.

¹¹ The data on cotton production and acreage (Tables 1 and 2), machine output and stock (Tables 3–5), and share of mechanized harvesting (Table 6) are drawn from secondary sources, which are approximately but not precisely consistent, even though they draw on a similar set of primary sources. The broad output trends and dominant role of the Uzbek republic are plain, even if precise magnitudes and weights in deriving Soviet Union-wide measures are not.

TABLE 1
COTTON PRODUCTION IN THE SOVIET REPUBLICS AND SUCCESSOR STATES,
1913–1999
(thousands of tons of raw cotton)

	Azeri ^a	Kazakh ^b	Kyrgyz	Tajik ^c	Turkmen ^d	Uzbek ^e	USSR
1913	64	^f	28	32	69	517	744
1940	154	^f	95	172	211	1,386	2,237
1953	388	^f	134	390	308	2,432	3,853
1956	352	^f	151	415	334	2,857	4,332
1960	366	^f	126	399	363	2,949	4,289
1965	355	^f	167	609	553	3,904	5,662
1970	336	^f	187	727	869	4,495	6,890
1975	450	^f	202	836	1,079	5,330	7,864
1980	884	^f	206	1,011	1,258	6,245	9,962
1985	788	^f	58	935	1,287	5,382	8,755
1988	616	^f	79	963	1,341	5,365	8,689
							Total
1992	336	246	52	515	1,290	4,129	6,568
1993	284	198	49	524	1,341	4,235	6,631
1994	284	208	54	531	1,283	3,936	6,296
1995	274	223	75	412	1,293	3,934	6,211
1996	274	183	73	318	436	3,350	4,634
1997	125	198	62	353	635	3,700	5,073
1998	113	162	75	385	707	3,220	4,662
1999	101	249	87	316	1,300	3,680	5,733

^a Azerbaijan after 1991.

^b Kazakhstan after 1991.

^c Tajikistan after 1991.

^d Turkmenistan after 1991.

^e Uzbekistan after 1991.

^f Kazakh production not identified in the source; it accounts for most of the residual.

Note: Other countries producing over a million tons in 1999 were China (11,490), United States (9,517), India (6,218), Pakistan (4,486), Turkey (2,093), Australia (1,728), Brazil (1,416), and Greece (1,185).

Sources: 1913–1988: Gleason, "Marketization," p. 67. 1992–1999: Food and Agricultural Organization website (www.fao.org).

TABLE 2
COTTON SOWN IN SOVIET CENTRAL ASIA, 1940–1988
(thousands of hectares)

Republic	1940	1950	1960	1965	1970	1980	1985	1988
Uzbek	924	1,098	1,387	1,550	1,709	1,878	1,990	2,017
Turkmen	150	153	222	257	397	508	561	636
Tajik	106	126	172	228	254	309	311	320
S. Kazakh	102	97	106	112	118	127	131	128
Kyrgyz	64	65	71	73	75	76	28	32
Total	1,345	1,539	1,958	2,220	2,553	2,897	3,021	3,133

Source: Craumer, "Agricultural Change," p. 144.

Political infighting hampered the refinement and improvement of harvester design during the 1950s. The Tajik leadership advocated planting in narrow rows and square clusters to increase cotton yields. The Uzbek leadership and cotton officials in Moscow opposed this “for respectable technical reasons *and* in order to maintain investment momentum behind new irrigation construction.”¹² Khrushchev resolved the debate in favor of the Tajik position, primarily because the Tajiks were fulfilling their cotton quotas while the Uzbeks were not, and because he was not keen on more investment in irrigation. Khrushchev also supported the Tajiks in their advocacy of horizontal-spindle machines; production of the SkhM-48 ceased in 1954. In a market economy there would have been technical competition and, in most cases, a convergence on the technology revealed to be superior.¹³ In the Soviet planned economy, the decision was ultimately taken by a poorly qualified autocrat, apparently on political grounds and without serious cost–benefit analysis.¹⁴ In any case, the need to design new horizontal-spindle machines for narrow rows set the machinery industry back several years.

Once production problems had been resolved in the late 1950s, both Soviet and outside observers expected mechanization to proceed rapidly. Annual output increased from a few hundred machines in the late 1950s to 3,200 in 1960, to a peak of 8,000 in 1965 (Table 3). The central planners favored mass production of a limited range of standardized machines, in defiance of the *kolkhozy*’s obvious diverse needs. In particular, even as late as 1970 no Soviet machines were suited to harvesting some varieties of long-staple cotton grown in the Turkmen and Tajik republics.¹⁵

These problems of politicization and bias in central planning can explain slight delays in the timing of the initial large-scale mechanization in the 1950s, and some geographical limitations on the spread of mechanical harvesters. However, they cannot explain the slow diffusion of mechanical harvesting after 1960, let alone its reversal after 1980.

¹² Hodnett, “Technology,” p. 77 (italics in original).

¹³ The ability to make such economic experiments is identified as a key advantage of capitalism over socialism by Rosenberg, *Exploring the Black Box*, pp. 87–108.

¹⁴ Khrushchev’s experience of agriculture was based on grain-farming regions of Ukraine and Russia. He had little sympathy for Central Asian farmers, whom he considered to be lazy and shiftless. Procurement prices for cotton were held back after 1954 because he considered them already too high relative to grain prices. After 1954 Khrushchev’s main goal in Central Asia was promotion of the Virgin Lands scheme to increase grain output in northern Kazakhstan; disruption of cotton-machinery production could free resources to produce tractors and grain harvesters. When cotton output failed to meet targets, he blamed the political leaders, and purged the leadership of every cotton-growing republic between December 1958 and May 1961. By contrast, under Brezhnev the political leadership was remarkably stable in Central Asia.

¹⁵ Hodnett, “Technology,” p. 78.

TABLE 3
ANNUAL OUTPUT OF COTTON HARVESTING MACHINES IN THE USSR, 1950–1979
(thousands)

Year	No.	Year	No.	Year	No.
1950	4,641	1960	3,184	1970	10,406
1951	9,810	1961	4,293	1971	6,706
1952	3,921	1962	6,090	1972	6,810
1953	3,346	1963	7,101	1973	6,725
1954	3,123	1964	7,000	1974	7,402
1955	555	1965	7,749	1975	7,572
1956	885	1966	7,204	1976	8,000
1957	102	1967	6,600	1977	8,650
1958	20	1968	7,731	1978	8,800
1959	486	1969	9,800	1979	9,100

Note: The Soviet figures reported by Gleason are in “standard units”: that is, two-rowed harvesters introduced in the early 1960s counted as two units and four-rowed harvesters introduced in the mid-1970s counted as four. Hodnett’s (“Technology,” p. 80) figures are similar to Gleason’s until 1966, but are lower for 1966–1970, presumably for this reason.

Source: Gleason, *Between Moscow*, p. 148.

POLITICS AND DIFFUSION

Gregory Gleason has provided the most sustained analysis of the slow mechanization of the Central Asian cotton harvest. He focuses on the labor-market effects of mechanization, arguing that it would have displaced the native population from the land and created a potential source of unrest in the towns of the region, or in other parts of the Soviet Union as they relocated in search of work. Moreover, the urbanization of Central Asia’s workforce would be associated with inflows of skilled labor from elsewhere in the Soviet Union. Neither politicians in Moscow nor the leadership in the Central Asian republics welcomed these consequences, and in the Brezhnev era they conspired to discourage mechanization in order to forestall its social consequences.¹⁶ Gleason concludes that “Moscow officials failed to order the agricultural machinery industry to produce that which was required for full mechanization,” and he predicted this would change with *perestroika*, when market forces would push *kolkhoz* managers to mechanize in order to cut costs and be competitive.

The idea that cotton *kolkhozy* were starved of machinery is belied by the production record. The stock of machines continued to increase into the 1980s,¹⁷ even after the share of cotton harvested by machine had begun to

¹⁶ Gleason sees evidence of this complicity in the longevity of Central Asian leaders between 1961 and 1982, when there was only one change in the top official of the five republics. He also sees local *kolkhoz* managers condoning the anti-mechanization strategy, because their influence was related to the number of workers on the collective. See Gleason, “Marketization”; the quotation in the next sentence is from p. 80.

¹⁷ See Table 4.

decline in every cotton-growing Soviet republic.¹⁸ Moreover, from early in the mechanization drive there is evidence that the share of cotton harvested by machine was far below its potential. In the Uzbek republic 2 percent of cotton was harvested by machine in 1958 and 11 percent in 1962, even though the stock of machines should have been sufficient to harvest a third of the crop.¹⁹ In 1977 two International Labor Organization economists visiting five *kolkhozy* in the Uzbek and Tajik republics were surprised at how little of the harvest was machine-picked, even on a showpiece collective that had 40 percent more mechanical harvesters per acre than the average for the Uzbek republic.²⁰

In contrast to the public-relations pictures of massed cotton harvesters bringing in the crop, there are frequent references in the less official literature to idle machinery. Over 800 machines (out of a total of 3,500) were reported idle during the 1970 cotton harvest in the Turkmen republic.²¹ Peter Craumer cites a figure of 19 percent of machines (i.e., around 2,000 units) standing idle during the 1982 harvest in the Turkmen republic.²²

The counterpart to unused machines is strong folk memories of masses of people picking cotton by hand in the 1970s and 1980s. Few outside observers made it to rural Central Asia during the cotton harvest, but in 1977 Azizur Rahman and Dharam Ghai “witnessed a great deal of cotton picking by hand,” even though the five *kolkhozy* they visited were showpiece collectives in locations relatively well-suited to mechanization.²³ Visiting Uzbekistan in the 1990s, I came across many people who had picked cotton as students in the 1970s and 1980s, and their recalled images too were of large numbers of people picking cotton by hand. In view of the prevailing pro-modernization ideology, the official data on the share of cotton picked by machine are likely to overstate the actual share, and the diffusion path is likely to have been even flatter than that presented in Figure 1.

Idle machinery is usually explained by the low priority given to repair shops in Soviet Central Asia, or more generally to central planners’ focus on production and neglect of maintenance. Cotton-harvesting machinery is everywhere subject to breakdown and in need of constant maintenance.²⁴

¹⁸ See Table 6.

¹⁹ Hodnett, “Technology,” p. 79.

²⁰ Khan and Ghai, *Collective Agriculture*, p. 113 n6. The tone of Khan and Ghai’s footnote is clearly that the “numbers do not add up.” Elsewhere in their report, they refer to being “told that there were technical problems of designing harvesters that would pick high quality cotton without waste” (p. 110 n26). This is a polite excuse rather than an explanation, because such problems are an inherent feature of mechanical cotton harvesters and conditions around Samarkand, where the comment was made, are about as favorable as possible for mechanical harvesting in Central Asia.

²¹ Hodnett, “Technology,” p. 74.

²² Craumer, “Agricultural Change,” p. 161.

²³ Khan and Ghai, *Collective Agriculture*, p. 110 n26.

²⁴ Hodnett (“Technology,” p. 113 n69) compares an Australian cotton farm he visited in 1971, where four specialized mechanics were employed full-time to look after 50 cotton harvesters, with the situa-

There is, however, a choice. If mechanization were highly efficient, then surely local resources would have been devoted to repair. Admittedly, maintaining the machines required skills that were scarce in Central Asia, but over the decades they could have been acquired if *kolkhoz* managers had wanted to avoid hand-picking. That Central Asian managers chose to leave machines idle suggests that they estimated the economic cost of idle machinery to be low.

THE MICROECONOMICS OF MECHANIZATION

The explanation for the slow diffusion of cotton harvesters lies in the incentive structure at the *kolkhoz* level. For any given producer, mechanization is desirable if the annual cost of a machine (C) is less than the value of the labor saved by mechanization

$$C < L_s \cdot w \cdot Q$$

where L_s is the days of labor saved per ton picked, w is the daily labor cost of hand pickers, and Q is the amount in tons that a machine can harvest in a year.²⁵ In the Soviet era prices were distorted and the distribution of resources did not depend on profitability, but these economic and technical variables still mattered. In this section I argue that the costs of hand-picking as perceived by *kolkhoz* decision-makers were less than the costs of mechanization.

Before 1958 mechanization decisions were made by central planners, and the machines were allocated to farms via machine tractor stations (MTS). After the 1958 MTS reform, however, the purchase of a machine was a cost to a farm, which would affect the incomes of *kolkhoz* members. The actual capital costs are difficult to calculate given the soft budget constraint they faced; C may have been low because debts incurred in their purchase were not enforced, although it is possible that managers perceived their debts to be real. Operating costs (fuel, lubricants, repairs, and so forth) were borne by the *kolkhoz*. Labor inputs for mechanized picking were very low, but there was a trade-off between labor expenditure and crop wastage, and wastage was always greater with machine-picking than with hand-picking.²⁶

tion in Soviet Central Asia, where many *kolkhozy* had no repair shop and the provision of centralized repair services was minimal after the 1958 reform of the Machine Tractor Station system.

²⁵ This formulation is used in the threshold-model literature of agricultural mechanization (see footnote 1), in contrast to the more common cost-benefit analysis using the discounted lifetime value of machines and present value of other flow variables. The yearly-cost approach masks the fact that the initial price of a machine must be paid, but (as argued below) it is unclear whether Soviet *kolkhozy* had any choice in the decision to accumulate machines. The annual formulation highlights the recurrent decision whether to pick mechanically or by hand.

²⁶ Whatley ("New Estimates," p. 201) reports that in the United States between 1949 and 1964 wastage with mechanical harvesting was fairly constant at 9 percent. Over the same period, wastage

Mechanization also reduced *kolkhoz* income because of the poorer-quality output, for which the producers received lower procurement prices.²⁷ Thus, C should include the fixed and variable costs plus the indirect costs of wastage and lower quality.

Decision-makers clearly saw the labor costs of hand-picking (w) as being sufficiently low relative to the costs of machines (C) that mechanization was resisted despite high values on L_s and Q . In the United States the labor required for cotton harvesting was reduced by 95 to 98 percent by mechanization, depending on climate and other field conditions, and this appears to have been true of Central Asia too.²⁸ The value of Q also varied by location.²⁹ In Soviet Central Asia the degree of resistance to mechanization varied, depending on the technical conditions reflected in L_s and Q ; for example, machine design was such that L_s and Q were lower and diffusion was slower in the Tajik republic. Nevertheless, the phenomenon of idle machines suggests a fairly ubiquitous tendency to consider costs not worth incurring in order to bring marginal machines into service.

The labor costs of hand-picking, as seen by *kolkhoz* decision-makers, were depressed by the varying status of *kolkhoz* members and by the state's ability to organize levies of students and urban workers. The main benefit from mechanization—the saving of back-breaking labor—was not shared equally. Despite the mass mobilization at harvest time, many *kolkhoz* members did not participate. Grey Hodnett cites a figure of 400,000 nonparticipants in the 1962 harvest in the Uzbek republic, when the total *kolkhoz* population was about a million. The *kolkhoz* members who did participate in the cotton harvest were mainly women; a plausible presumption is that *kolkhoz* managers perceived their female workers as having a lower opportunity cost than most male members.

Soviet Central Asia was often described as a region of surplus labor, in contrast to the European parts of the Soviet Union. Although there was by definition no unemployment, Western observers found substantial underem-

with hand-picking was between 2.5 and 5 percent, rising over time as the average age of pickers increased.

²⁷ The difference was about 10 percent in 1963 (Hodnett, "Technology," p. 115 n93).

²⁸ On the United States, see Street, *New Revolution*, p. 170; and Whatley, "New Estimates," p. 201. In 1999 in Uzbekistan cotton-harvester drivers were paid 100–200 *sums* per ton picked, whereas hand pickers were paid 8–9 *sums* per kilogram, so that the reduction in labor costs from mechanization was at least 97.5 percent.

²⁹ Annual use of cotton-harvesting machines in the United States in the 1950s and 1960s varied from 225 hours in the southeast, to 350 hours in the Mississippi Delta, to 500 in the west; see Whatley, "New Estimates," p. 215. The main reason for this discrepancy was the drier and more reliable climate in the west compared to the mud and morning mist of the southeast coastal regions. Musoke and Olmstead ("Rise") emphasize larger farm size and climate as reasons why Californian cotton farms were best-suited to mechanical harvesting in the United States. Similar features in the core cotton-growing areas of Central Asia suggest that neither physical conditions nor *kolkhoz* fragmentation are plausible explanations for the slow diffusion of machine-picking.

ployment.³⁰ One complication is the seasonality of agricultural work, and especially the heavy demands during the cotton harvest. In the mid-1980s over half of Uzbek cotton and three-quarters of Tajik cotton was hand-picked, for which students and industrial workers were drafted for six to eight weeks.³¹ The main social cost of these levies was the disruption of industry and education, but the direct cost to the *kolkhoz* was small: in 1972 these casual workers were paid five kopeks per kilogram picked.

Mechanization would have had further effects on *kolkhoz* organization. In particular, mechanization would make more economic sense if greater acreage were devoted to cotton and planting patterns devised to ease mechanical harvesting. Such changes in sowing patterns were resisted by *kolkhoz* members because they threatened to upset the established division between collective land and private plots. The private plots provided insurance against sudden policy changes and other negative shocks to living standards. Although hard evidence on the value of private plots in Central Asia is difficult to come by, Hodnett claims that they probably accounted for at least a third of average family income in the 1960s; Nancy Lubin has estimated that private plots accounted for a fifth of Central Asian agricultural output and a quarter of *kolkhoz* families' income circa 1980.³² Sheila Marnie shows a big range by republic and by family income in 1989: in the Uzbek republic, for instance, for the poorest families (with per capita monthly income below 75 rubles) private plots accounted for 19–20 percent of family income, whereas for families with per capita income above 200 rubles private plots accounted for 32 percent of income.³³ Thus, in the biggest cotton-producing republic all *kolkhoz* families might resist any threat to their private plots, but the wealthier—and presumably more influential—families had most to lose.

In sum, many *kolkhoz* managers considered the costs of mechanization to outweigh the benefits, even though their “soft” budget constraints rendered the

³⁰ Dienes (*Soviet Asia*, p. 131) reviews some of this literature, concluding that in 1979 surplus labor was about 1.1 million in the Kyrgyz, Tajik, Turkmen, and Uzbek republics combined, and around 315,000 in the Kazakh republic. Marnie (“Soviet Labor Market,” pp. 203–05) estimates that in 1984 over a million people were voluntarily or involuntarily unemployed in the Uzbek republic, the core of the Soviet cotton economy, and the non-employed amounted to 14 percent of the working-age population, compared to 5.5 percent in the Russian republic. Klugman (“Wages,” p. 34), however, points to large regional variations in Uzbekistan between cotton-growing areas, such as the labor-scarce Dzijak region, and the surplus-labor Ferghana Valley.

³¹ In 1986 and 1987, 650,000 to 700,000 schoolchildren, 140,000 college and vocational school students, and an unreported number of urban workers harvested cotton in the Uzbek republic (Craumer, “Agricultural Change,” p. 162). In the Tajik republic over 300,000 students and industrial workers were drafted during harvest seasons in the mid-1980s for one-and-a-half to two months cotton picking (Dienes, *Soviet Asia*, p. 130).

³² Hodnett, “Technology,” pp. 85–86; and Lubin, *Labor and Nationality*, pp. 181–82 and 188.

³³ Marnie, “Soviet Labor Market,” p. 223. This progressivity was more pronounced in the Tajik republic, rising from 16 percent to 45 percent. In the Kyrgyz and Turkmen republics, the share fell as family income rose. The share of family income coming from private plots was much lower in the Turkmen republic (8–16 percent) than in the other three republics covered by Marnie.

machines themselves essentially free. One reason might be that their objectives focused on meeting output targets, so that wastage costs, while relatively minor to a firm in a market economy, loomed large in the Soviet context; mechanization would in effect require planting more hectares with cotton. Also, managers' loyalty to their male colleagues would have discouraged disruption of the private-plot system, and led to little weight being placed on the arduous labor done by others. In the specific institutional context of Soviet Central Asia, central planners and *kolkhoz* managers were acting at cross-purposes with respect to mechanization, and the question arises of whether the resistance to mechanization was desirable on any grounds other than the local decision-makers' self-interest within the Soviet system.

COST-BENEFIT ANALYSIS

The previous section investigated the mechanization decision from the perspective of the most influential members of the *kolkhoz*. This section tries to make the same calculation on the basis of shadow prices. Was mechanization appropriate in Soviet Central Asia given the region's resource endowments?

One approach to this question is to assume technical parameters and capital costs from the much-studied U.S. case. According to Warren Whatley, in 1964 the total expected cost of machine-harvesting cotton ranged from 3.1 cents per pound in California to 8.9 cents in North Carolina.³⁴ If the technical characteristics of Soviet and U.S. machines (L_s and Q) were similar, then the key issue is whether shadow labor costs were below this range.³⁵ The casual harvest-time wage rate of five kopeks per kilogram was equivalent to around two U.S. cents per pound at official exchange rates, and even less at other exchange rates preferred by Sovietologists in the 1960s.³⁶ Thus, it seems probable that labor was sufficiently abundant in Soviet Central Asia for hand-picking to be the most efficient technique, even if physical conditions were as favorable to mechanization as in the least-cost U.S. region.

This conclusion is consistent with international evidence. In the southern United States in the late 1950s, the labor costs of hand-picking cotton were

³⁴ Whatley's estimates draw on earlier work by Street and a 1969 University of Chicago Ph.D. dissertation by Frank Maier; see Whatley, "New Estimates"; and Street, *New Revolution*.

³⁵ This is not a very stringent test. Insofar as U.S. machine-makers offered a wider range of cotton harvesters than Soviet producers, Soviet labor costs would need to have been significantly higher than three U.S. cents per pound to justify widespread mechanization.

³⁶ This was not a market-determined wage, but the low wage is consistent with the underemployment evidence presented in the previous section. Thirty years later, labor was still abundant enough to make mechanization uneconomic; in the 1998 harvest season in Uzbekistan cotton pickers were paid five *sum* per kilogram, which was just over two U.S. cents per pound at the official exchange rate and less than one cent at the market exchange rate; see Pomfret, "Agrarian Reform."

over five cents per pound.³⁷ Australia, the other high-wage cotton-growing country, also mechanized harvesting. Major producers such as India, China, and Pakistan, however, continue to harvest by hand because their labor costs do not justify mechanization.³⁸ Soviet Central Asia was between these extremes of labor costs, and closer to Egypt or Iran or Turkey, none of which has mechanized the cotton harvest.

One cannot, of course, rule out externalities. The social disruption of mechanization would have been considerable,³⁹ but not necessarily negative and, as emphasized above, there is little evidence of policymakers delaying mechanization for this reason. More plausibly, Soviet planners may have placed great weight on the propaganda benefits of modernization. An economic price was, however, paid for any such psychic benefits.

How high was this price? The phenomenon of idle machines suggests that their true economic value was close to zero, and this is supported by the collapse of sales after 1991. In that case the cost of premature mechanization was the resource cost of building the machines. Over 60,000 machines were produced in the 1960s (Table 3) and, although I have no data on depreciation rates, the numbers in Table 4 suggest that this flow was perhaps maintained through the 1970s and declined in the 1980s, before collapsing to a few hundred per year in the late 1990s (Table 5).⁴⁰ Soviet prices tell us little about the resources going into each machine, because input prices, transport costs, and output prices for producer goods were all meaningless in the centrally planned economy. During the 1960s the list prices for generic standard-model cotton pickers in the United States ranged from \$6,000 to \$10,000.⁴¹ Given the competitive nature of the U.S. industry, this could be considered the “world price” of a standard machine and, if Soviet machines were of the same quality, then it provides a shadow price. Thus, during the 1960s the opportunity cost of premature mechanization of cotton-picking was in the range of \$360–600 million. The amount may have been slightly

³⁷ Labor costs included not just the minimum wage payments of about \$3.50 per hundredweight, but also recruitment and organizing costs (0.86 and 1.16 cents per pound); see Whatley, “New Estimates,” p. 211.

³⁸ In 1999 the countries with the largest cotton production were China, the United States, India, Pakistan, Uzbekistan, Turkey, Australia, Brazil, Turkmenistan, and Greece (Table 1).

³⁹ In the southern United States the mechanization of cotton and subsequent release of unskilled labor was arguably the greatest single economic and social event of the twentieth century, transforming not only the cotton sector but also the entire labor market and social structure, leading to large-scale migration to the northern United States and reinforcing demands for civil rights.

⁴⁰ In interviews at the Tashkent Institute of Engineers for Irrigation and Agricultural Mechanization (TIEIAM) in 1997 I was told that 2,000 cotton-picking machines were produced per year in the 1980s. Output dropped to very low levels in the early 1990s, although TIEIAM staff explained that this was due to input supply disruptions (especially steel) and technical problems which were being resolved by negotiating a joint venture with a U.S. producer. With a total academic staff of 422, and 514 students registered in its Faculty of Agricultural Mechanization, TIEIAM clearly maintains the tradition of central advocacy of mechanization.

⁴¹ Whatley, “New Estimates,” p. 209.

TABLE 4
STOCK OF COTTON-HARVESTING MACHINES, 1960–1986
(thousands)

Republic	1960	1965	1970	1975	1980	1986
Uzbek	8.30	21.80	26.10	28.70	36.60	37.90
Turkmen	0.68	3.30	3.50	6.50	9.30	10.90
Tajik	0.17	2.23	2.85	2.91	3.42	4.11
Kazakh	0.70	?	2.80	?	2.50	2.60
Kyrgyz	0.14	1.64	1.74	1.27	1.05	0.74
Total	9.99	?	36.99	?	52.87	56.25

Source: Craumer, "Agricultural Change," p. 161.

less in the next two decades, but it is unlikely that the total (undiscounted) cost at 1960s prices was less than \$1 billion.⁴²

CONCLUSIONS

Labor productivity in Soviet Central Asia was very low. Cotton output per day of labor in 1953 was even lower in the Soviet Union than in Egypt.⁴³ Labor productivity increased during the 1950s and 1960s, but it fell in all the cotton-growing republics between 1970 and 1987.⁴⁴ Despite the large expenditure on irrigation, machinery, and fertilizers, the returns to both land and labor used in cotton production were diminishing in the final two decades of the Soviet Union, and the cotton economy was imposing huge environmental costs as chemical fertilizers drained into the rivers and irrigation projects cut off the flow of water to the Aral Sea.⁴⁵ Soviet planners recognized the low level of labor productivity and saw the need for mechanization, but low opportunity cost of labor is a reason for doubting the appropriateness of labor-saving investment.

Politicization and central planning delayed the development of the cotton-harvester industry in the 1950s; once it did take off, the system's rigidity and biases restricted the development of technical improvements and of repair facilities. These are, however, minor features of the story of the anemic

⁴² Because some machines had positive value in relatively labor-scarce areas such as Dzjizak this could be an overestimate, but in other respects it is a minimum estimate. The U.S. prices are for bottom-of-the-line one-row pickers, whereas Soviet output included two-row pickers (which were twice as expensive as one-row pickers in the United States) and other non-standard models. As noted in Table 3, data on machine production in the 1950s and 1960s are imprecise about quality. Moreover, substantial costs were incurred in the design and retooling associated with the SkhM-48 and subsequent shift to horizontal-spindle machines.

⁴³ Economic Commission for Europe, "Regional Policy," p. 60; and Hodnett, "Technology," p. 73.

⁴⁴ Craumer, "Agricultural Change," p. 159.

⁴⁵ In March 1989 Gorbachev was reported in *Pravda* as complaining that over the previous 20 years in Uzbekistan 1.6 million new hectares of irrigated land had been created and productive forces in agriculture had increased sixfold, but gross production was up only 78 percent; see Gleason, "Marketization," p. 72.

TABLE 5
ANNUAL OUTPUT OF COTTON-HARVESTING MACHINES IN UZBEKISTAN, 1994–1999

Year	No.
1994	651
1995	1,121
1996	863
1997	1,049
1998	351
1999	278

Note: So far as I am aware, no cotton harvesters were produced elsewhere in the former USSR; so these figures are comparable with Table 3.

Source: Ministry of Macroeconomics and Statistics data reported in *Uzbek Economic Trends*, January–March 2000, p. 104.

diffusion of mechanical harvesting in Soviet Central Asia. The main point is that, given the technical parameters and abundance of labor in Soviet Central Asia, hand-picking was more economical than machine-picking. Even with machines essentially free (in the sense that there was a stock and no second-hand market), *kolkhoz* managers preferred to leave them idle. Planners and politicians had little idea of how their strategy for increasing labor productivity was received at the *kolkhoz* level.⁴⁶

With over a decade of post-Soviet experience, we have a huge advantage over writers who tried to explain cotton mechanization during the Soviet era. Nevertheless, it is surprising just how universally accepted was the premise that mechanization was a source of improved efficiency. Observers cited the difference in labor requirements between hand-picking and machine-picking, without considering the capital costs and other factors. Since the end of central planning in the new independent states, there appears to have been a continuing decline in mechanical harvesting; at the very least, there has not been the dramatic shift to machine-picking which Gleason predicted would be the inevitable outcome as market forces became more important under *perestroika*.⁴⁷ (See Table 6 for the year-by-year percentages of cotton actually harvested by machine.) The implication is that *kolkhoz* members, who opposed mechanization out of a narrow self-interest shaped by distorted Soviet prices and other incentives, actually produced the

⁴⁶ Irrigation projects, the other huge capital investment in Central Asian agriculture, also failed to distinguish between *kolkhoz*-level incentives and social welfare, but in this case *kolkhozy* and central planners tended to be on the same side. Irrigation projects were generally supported by *kolkhoz* members, who saw private benefits from free or heavily subsidized water, which helped them to achieve cotton-output targets as well as improving their private plots, with little cost to them. Little attention was paid to effective use of the water, a scarce resource in the Central Asian desert, or to the environmental costs of existing and planned irrigation projects. Even as late as the mid-1980s official opinion was still in denial as to the costs of desiccation of the Aral Sea, and Chernenko was still considering diversion of Siberian rivers. The common feature was the grand commitment to modernization without attention to complexities “on the ground.”

⁴⁷ Gleason, “Marketization.”

TABLE 6
 PERCENTAGE OF COTTON HARVESTED BY MACHINE IN THE MAIN COTTON-
 PRODUCING SOVIET REPUBLICS, 1965–1988

	Uzbek	Turkmen	Tajik	Kazakh	Kyrgyz
1965	23	?	14	21	33
1970	33	32	22	41	39
1975	46	47	28	69	62
1980	63	52	36	63	51
1981	68	49	29	51	61
1982	54	41	22	45	63
1983	34	43	12	43	49
1984	31	26	11	39	60
1985	40	52	13	76	23
1986	42	47	22	?	69
1987	45	?	20	57	69
1988	47	65	24	78	?

Note: The USSR points in Figure 1 are weighted by republican production levels, from Table 1. Hodnett (“Technology,” p. 79) gives similar figures: at “the end of the 1960s” 33 percent of the entire Soviet crop was machine-harvested, with variation across republics: Kyrgyz 39 percent (1970); Turkmen 33 percent (1970); Tajik 21 percent (1969); Azeri 9 percent (1965); and Uzbek 1.7 percent (1955), 2 percent (1958), 11 percent (1962), 24 percent (1965), 29 percent (1969), and 34 percent (1970).

Source: Craumer, “Agricultural Change,” p. 161.

economically efficient outcome in view of true relative factor prices in labor-abundant Central Asia. Cotton-picking remains back-breaking work, but in the more market-oriented economies of the 1990s the demand for cotton-harvesting machines virtually disappeared and the supply of labor was plentiful even at the low wages.⁴⁸

The role of central planners in pushing cotton mechanization was similar to that prescribed by advocates of public policy to accelerate technical diffusion. In the long run, as incomes rise, machine-picking displaces hand-picking. That this process did not occur as smoothly or rapidly as planned was not primarily due to the incompetence or deviousness of politicians or planners, but rather due to resistance at the *kolkhoz* level. The true cost of state-directed diffusion was not that the planners failed to speed up diffusion, but that they did it too far ahead of its time. The costs in terms of wasted resources in machine production were large, amounting to at least \$1 billion at 1960s prices, even under conservative assumptions.

Accelerating technical diffusion, especially when it appears to be obstructed by scale barriers associated with expensive equipment, is often advanced as a reason for government intervention, and not just in centrally planned economies. In newly independent states in the 1950s and 1960s,

⁴⁸ In the 1998 harvest season the base rate in Uzbekistan was only five *sum* per kilogram, or about \$5 per day at the market exchange rate (Pomfret, “Agrarian Reform,” p. 281). Apostolou (“Uzbek Model”) reports that 96.5 percent of Uzbekistan’s 1999 cotton harvest was picked by hand, and that out of cotton export earnings of \$884 million just \$3 million was accounted for by labor costs.

technological catch-up was one of the arguments for state-supported industrialization. Even a well-managed economy like South Korea's fell into this trap with its heavy-industry drive of the late 1970s, aimed at speeding the ascent up the technical ladder, but leading instead to an embarrassing climb-down by policymakers. In high-income market economies a costly example was the French and British governments' success in providing their national airlines with a supersonic aircraft when the market failed to do so. British Airways and Air France, each forced to take seven Concorde, were unhappy even when the aircraft were sold to them for one franc; the premium they could charge supersonic passengers was inadequate to cover even the operating costs.⁴⁹ Supersonic travel will surely become economical someday, just as Central Asian cotton will eventually be picked by machine. But anticipating the future can be a costly folly.

⁴⁹ By the end of 1978 the British and French governments had spent \$4.28 billion to build two prototypes and 14 commercial planes. The two national airlines each made operating losses on their seven Concorde, so that in 1981 both national governments were subsidizing Concorde operations; see Feldman, *Concorde and Dissent*, pp. 83–120. Public spending on Concorde is a lower-bound cost estimate because it understates the opportunity cost of many valuable resources.

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