Fertilizer Markets and Allocative Efficiency

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This is a modification of the paper "Allocative Efficiency in Russian Agriculture: The Case of Fertilizer and Grain" published in the American Journal of Agricultural Economics, 85(8): 1228-1233 (Nov. 2003). The authors thanks Carlos Arnade and Michael Trueblood for helpful comments, as well as Olga Melyukhina of the OECD for assistance with data, and bear any responsibility for any remaining flaws. The views expressed are the authors' alone and do not represent the official views or policies of their employing institutions.

1. Introduction

During Russia's economic transition, the amount of fertilizer (as well as other tradable inputs such as fuel) used in agricultural production has fallen substantially. Mineral fertilizer use in 2000 was 86 percent lower than in 1990, while since the mid 1990s Russia has exported more than 80 percent of its fertilizer output. This article examines the allocative efficiency of Russian use of fertilizer to produce grain, assessed from the point of view of both domestic and world market prices. We use the results to examine whether fertilizer is being used at its optimal level, and whether the major changes in the volumes of fertilizer use and trade during transition have been economically rational. Implications for agricultural policy in Russia are then discussed.

2. Methods and Data

The method used to assess the allocative efficiency of Russian fertilizer use in producing grain is to compare the fertilizer's marginal factor cost (MFC_f) with the value of its marginal product in grain production ($VMPf_g$). Given that Russian farms appear to be price takers in their purchase of fertilizer, we initially assume that fertilizer's *MFC* to farms equals its purchase price (P_f). Russian grain producers will be using fertilizer efficiently (and at the profit-maximizing level) when:

$$P_f = MP^f_{g*} P_g$$

where MPf_g is the fertilizer's marginal product in grain production, and Pg the price at which the producers sell their grain, with their product being $VMPf_g$. If $P_f > (<)\ VMP^f_g$, we will refer to the situation as one of disequilibrium, in which the use of fertilizer in grain production should decrease (increase) in order to improve allocative efficiency.

We investigate Russian fertilizer/grain use in two specific years—1990 (representing the immediate pre-reform period) and 2000. The test for efficiency will be done using both domestic and trade prices. The domestic prices are estimates of what Russian farms paid for fertilizer and received for grain, and will indicate whether Russian farms were optimizing given the actual prices they faced. The trade prices used will be the prices at which Russian fertilizer and grain traded (or would have traded if exported) on the world market, and will indicate whether the *Russian economy* was optimizing when measured against opportunity cost.

The source for Russian domestic fertilizer prices is *Tseni v Rossii* (Russian Federation State Committee for Statistics (a), 1996, 1998, 2000). The fertilizer trade prices are Russian export unit values for fertilizer in U.S. dollars from *Tamozhennaia Statistika* (Russian Federation State Customs Committee). Because Russia's trade data value both imports and exports in U.S. dollars, an exchange rate is not needed to determine dollar values. In computing the aggregate annual trade prices for fertilizer, as well as the aggregate domestic prices, we weight each of the three main types of fertilizer (nitrogen, potash, and phosphate) by their shares in the total tonnage of fertilizer used in Russian grain production.

During the transition period, Russian fertilizer export prices have fluctuated considerably, largely following changes in world energy prices. For example, in 2000 Russia's unit value for fertilizer exports was relatively low at $74 at ton, compared to the average annual unit value for the country's fertilizer exports over 1994-2002 of $95 a ton. Trade prices specific to any given year can be misleading as representative of a longer period of time. Therefore, in our allocative efficiency tests for both 1990 and 2000, we have the fertilizer trade price equal the average annual export unit values of fertilizer over 1994-2002 (Russia began releasing official foreign trade data in 1994).

The source for Russian domestic grain prices is also *Tseni v Rossii*. For trade prices, measurement is more complicated. Russia's grain trade prices have also fluctuated during the transition period (following the world market). In the allocative efficiency tests, we therefore base the grain trade prices on prices covering the period 1990-2002. However, in only a few years (1997, 2001, and 2002) did Russia export enough grain such that its export prices (from *Tamozhennaia Statistika*) could adequately represent the prices at which Russia could have exported large quantities of grain. For other years, we base the Russian grain trade price on U.S. wheat export fob prices (Economic Research Service), since Russian grain exports are mainly wheat. In 1997, 2001, and 2002 Russian wheat export unit values were 40 percent below U.S. wheat export prices, probably due to quality differences and the product mix. Thus, we discount the U.S. wheat export prices by 40 percent to obtain our estimates of Russian wheat export prices.

For farm-level analysis, the relevant grain trade price is that part of the export fob price that farms receive. A major problem in Russian agriculture is that, because of incompletely developed physical and institutional infrastructure (including systems of market information and commercial law), the internal movement of agricultural commodities involves high transport and transaction costs (Wehrheim et al.). Ukrainian agriculture has similar problems, and Striewe finds that in the late 1990s grain-producing farms received prices equal to only about 45 percent of the grain's export fob price (indicating a discount of 55 percent), compared to the 75 percent of the export fob price obtained by German grain producers. (Post-harvest losses are taken into account in determining the real prices received.) U.S. wheat farmers receive prices equal to about 80 percent of wheat's export fob price (ERS). In light of the evidence for Ukraine, Germany, and the United States, we discount the Russian grain export fob price by a further 40 percent to obtain the farm-level trade price.

To obtain estimates of MP^f_g, we use several econometric studies of Russian agricultural production functions that have estimated output elasticities with respect to fertilizer. Multiplying these elasticities by the average product of fertilizer yields the estimated *MP* values. Table 1 presents the output/fertilizer elasticities computed by these studies. The first four studies are more relevant for determining *MP* values for our allocative efficiency test for

1990, while the last two studies are more relevant for 2000. Koopman has the drawback for our purposes of covering Soviet, as opposed to only, Russian agriculture, while Lerman et al. covers all the Soviet "northern republics" (Lithuania, Latvia, Estonia, Russia, Ukraine, Belarus, Moldova, and Kazakstan). Lerman et al., Koopman, and Sotnikov also have the liability that they cover livestock output in addition to crops. Therefore, the output/fertilizer elasticities implied by the latter studies are underestimates for our purposes.

For use for 1990, the fertilizer elasticities of Lerman et al. and Koopman could be biased upward. After years of high growth in fertilizer application during the Soviet period, fertilizer use in 1990 was substantially higher than average annual use for the period employed in estimating the production functions. This means the *MP* of fertilizer was probably lower relative to previous years. On the other hand, for use for 1990, the fertilizer elasticities of Sotnikov and Sedik, Trueblood, and Arnade could be biased downward. Russia's price liberalization that began in 1992 quickly worsened agricultural producers' terms of trade, such that fertilizer use began to fall heavily.

Table 1. Studies that Estimate Russian Agricultural Production Function

Study	Grain/Fertilzers Elasticities	Coverage
Lerman et al	0.143	Soviet Agriculture output over 1965-90*
Koopman	0.225	Soviet Agriculture output over 1965-85
Sotnikov	0.07	Russian agriculture output over 1990-95
Sedik et al	0.075	Russian agriculture output over 1991-95
Osborn and Trueblood	0.025	Russian crop output over 1993-98
BASIS project	0.06	Russian crop output in 3 regions, 2001**

* Covers the "northern republics" of Lithuania, Latvia, Estonia, Russia, Ukraine, Belarus, Moldova, Kazakhstan? ** The regions are Rostov, Ivanovo, and Nizhni Novgorod

For 1990 we use a *MP* value derived from Sedik, Trueblood, and Arnade, and for 2000 a MP value from the work by Osborne and Trueblood. We choose these two studies because they both were done at USDA's Economic Research Service (with Trueblood being a co-author of both), and therefore have the benefit of being methodologically consistent. The two studies have the additional advantages of being confined to Russian crop output, and the output/fertilizer elasticities of the two studies are consistent. In 2000, Russia used 20 kilograms of fertilizer per hectare of grain area, compared to 81 kilograms in 1990 (Russian Federation State Committee for Statistics (b), 2001, p. 405). Thus, one would expect the output/fertilizer elasticity to fall, as it does in the two studies by two-thirds. From Sedik, Trueblood, and Arnade, we get a *MP* value of 1.5 tons of grain per ton of fertilizer used, and from Osborne and Trueblood we get a value of 1.85.

Calculations based on the results of Sedik, Trueblood, and Arnade and Osborne and Trueblood give likely lower bound values for fertilizer's *MP*. Because this might bias the test results in the direction of apparent domestic overuse of fertilizer, we also use in table 2 a set of higher values for fertilizer's *MP* and *VMP*, based on the results of the other studies cited. For 1990 we use a value for *MP* of 3.5, based on the output/fertilizer elasticities from Lerman et al. and Koopman. For 2000 we base the *MP* value on the elasticity from the BASIS project, which results in a MP value of 4.

3. Results

The results from Table 2 for 2000 show that whether the high or low *MP* value is used, fertilizer's *VMP* greatly exceeds its domestic price. The results suggest that an additional ton of fertilizer to produce grain would increase farms' revenue two to four times the fertilizer's cost. Farms are using fertilizer at far below the profit-maximizing volume.

Table 2. The Allocative Efficiency of Using Fertilizer to Produce Russian Grain

Year and Price	$P_{\text{fertilizers}}$	MP	P_{grain}	*VMP*	$VMP\text{-}P_{fertilizers}$	$(VMP\text{-}P_{\text{fertilizers}})/\ P_{fertilizers}$
2000, low						
Domestic	1,597	1.85	1,865	3,450	1,853	1,16
Trade	95	1.85	54	94	-1	-
2000, high						
Domestic	1,597	4	1,865	7,460	5,863	3.67
Trade	95	4	51	204	109	1.15
1990, low						
Domestic	76	1.5	281	422	346	4.55
Trade	95	1.5	51	77	-19	-
1990, high						
Domestic	76	3.5	281	984	908	11.94
Trade	95	3.5	51	179	84	0.88

Source: *Tseni v Rossii* and authors' calculations.

Note: Prices for both fertilizer and grain are per ton, and the *MP* of fertilizer gives tons of grain produced per ton of fertilizer. Domestic prices are in rubles, trade prices in U.S. dollars P means price; *MP* marginal product; and *VMP* value of marginal product.

What could explain the apparent large disequilibrium? We consider the following possible explanations: (1) misallocation of resources by farm managers; (2) farms are in fact at (or much closer to) the profit-maximizing equilibrium, but we have either overestimated the *MP* of fertilizer or underestimated its cost to farms; (3) farms lack the working capital, to be financed by either their own revenue or credit, to buy fertilizer at market prices; and (4) farms are willing to pay higher prices to obtain more fertilizer, but suppliers impose quantity constraints on sales.

Managerial misallocation could in principle result as easily in over- as underuse of fertilizer. In his classic study of U.S. agriculture, Griliches (1963) took his estimated excess of fertilizer *VMP* over factor price as evidence of disequilibrium in the form of fertilizer underuse. What made this explanation highly plausible in the U.S. context is the rapid growth in fertilizer use that occurred during 1950-1980. Fertilizer use in Russian agriculture also rose substantially during the postwar period, with total use of mineral fertilizer growing from 3.3 million metric tons (mmt) in 1970 to 9.9 mmt in 1990 (Russian Federation State Committee for Statistics (b), 2001, p. 405). During the transition period, however, Russian fertilizer use has plummeted, to only 1.4 mmt (mineral fertilizer) in 2000. Table 2 indicates that in 1990 Russian fertilizer was even more underutilized from the point of view of domestic prices than in 2000, with the returns to farm profitability of using more fertilizer being from four to twelve times the fertilizer's price. During the Soviet period, however, the state set prices for both agricultural inputs and outputs, and allocated inputs. Thus, table 2 cannot be used to demonstrate misallocation in the sense of market disequilibrium that could be corrected simply by the passage of time or by the introduction of more astute farm managers.

The studies on which we base our *MP* values might overstate the actual *MP* values. One reason is the classic "management bias" problem (see Mundlak). Farm managers most likely vary in their abilities, and the more efficient ones generate a higher *MP* and therefore use more fertilizer. Thus, a cross-sectional regression overstates the MP of fertilizer on an average farm -- the estimated output elasticity measures the gain in output between poorly managed and better managed farms and attributes to fertilizer what properly accrues to management. However, the fact that we use as a lower bound the smallest of a range of quite different estimates of fertilizer *MP*s reduces the chances that our lower bound is too high.

We might also be underestimating farms' total cost of *using* fertilizer, which involves the cost of not only purchasing, but also applying, the fertilizer. Application costs would ideally be incorporated in the machinery and labor input variables used to estimate the production functions. All of the studies cited, however, use the Cobb-Douglas functional form, which assumes that all inputs are substitutes and thereby does not allow, for example, any machinery and labor to be input complements of fertilizer. Epstein (BASIS project) estimates that the application costs of fertilizer could equal 20 percent of fertilizer's price. However, the disequilibrium we estimate is so large that increasing the fertilizer marginal factor cost by 20 percent would not come close to reversing the finding of underuse of fertilizer.

Another cause of the disequilibrium could be financial constraints, such that farms lack the working capital, financed either from their own revenues or credit, to purchase inputs. A well-operating credit system does not yet exist for Russian agriculture, as the unprofitability of most Russian farms during the transition period has discouraged commercial lending to agriculture.

The last possible explanation for the disequilibrium is that farms are willing to pay higher prices for fertilizer, but suppliers are averse to selling at even greater prices. This explanation appears to be the most convincing. Evidence (Interfax) indicates that to obtain fertilizer, Russian farms usually need the help of higher authority, such as their regional government, which either pays higher prices for the fertilizer or commands delivery at low prices. Regional governments often "sell" fertilizer to farms at attractively low prices, in return for the farms' commitment to sell back their output, or at least sell within the region.

Table 2 shows that the large gap between fertilizer's *VMP* (as conventionally computed) and price has fallen substantially during transition. The main reason is that the ratio of the price of grain to fertilizer (both in tons) has dropped significantly, from 3.7 in 1990 to 1.17 in 2000. This fall coincides with the steep decline in Russian agricultural producers' overall terms of trade during transition. Does this suggest that further deterioration in grain producers' terms of trade vis-à-vis fertilizer (and perhaps other inputs as well) that is inherent to the reform process might be in store for Russian farms, which would eliminate any apparent underuse of fertilizer from the point of view of allocative efficiency and farm profitability?

Analysis of the allocative efficiency of fertilizer use when assessed from the point of view of trade, rather than domestic, prices indicates that this could well be the case -- that is, that fertilizer is not being underused from the national viewpoint when world prices are the benchmark. Table 2 shows that in 2000, when the low estimate of fertilizer's *MP* is used and both fertilizer and trade prices are measured at their export trade values, fertilizer's trade price almost exactly equals its *VMP*. As such, fertilizer use is at its optimum. In 1990, fertilizer's trade price exceeded the *VMP* (at the low *MP* value), indicating fertilizer *overuse*. When the

high *MP* value is used for both 1990 and 2000, we again get the result that fertilizer is underused (price < *VMP*). For reasons discussed in the previous section, we believe that the lower *MP* values (based on Sedik, Trueblood, and Arnade and Osborne and Trueblood) are more likely to be correct. In short, relative to trade prices, fertilizer does not appear to have been underused during the transition period.

The conclusion that fertilizer was being overused at the start of transition from the point of view of foreign trade is consistent with both the large drop in Russian fertilizer use during transition (both in general and for grain), and the fact that since the mid 1990s Russia has exported more than 80 percent of its fertilizer output. The conclusion that fertilizer use in grain production is currently at (or at least very close to) its optimum with respect to trade prices, even while a large disequilibrium appears to exist with respect to domestic prices, helps explain why Russian farms cannot obtain more fertilizer at existing domestic prices. Trade prices for fertilizer are so high relative to domestic prices that Russian fertilizer producers have much greater incentive to produce for export than for domestic sale. In 2000 the ratio of the trade prices (per ton) of fertilizer to grain (farmgate) was 1.86, while the ratio for domestic prices (grain at farmgate) was 0.86. More specifically, table 2 shows that in 2000 Russian fertilizer producers receive $95 per ton of output sold on the world market, but only $57 if they sell to domestic users of fertilizer (1,597 rubles per ton converted to dollars using an exchange rate for 2000 of 28 rubles to the dollar). Another export incentive for Russian fertilizer producers is that they can keep, and invest, their earnings abroad. These fertilizer export inducements explain why Russian farms need the help of nonmarket forces, such as their regional government, to obtain fertilizer supplies.

Russian domestic fertilizer markets therefore appear to reflect not only a disequilibrium between input prices and the inputs' *VMP*, but also the fact that domestic prices differ so strongly from (relative) trade prices. Since transition began in the early 1990s, Russian farms' domestic grain to fertilizer terms of trade have been steadily worsening, moving closer to terms of trade given by world trade prices. Yet, the price data for 2000 show that this reform-driven price adjustment is not yet complete. Our results suggest that if the process were immediately completed such that world trade prices wholly determined domestic prices, Russian farms currently would not be underusing fertilizer.

What are the policy implications of our results? If Russia wishes to maximize the gains from trade and integration into world markets, the large disparity between domestic and world (relative) prices will continue generating domestic signals and incentives to use resources in a way that reduces these potential gains. A more specific improvement would be to make internal agricultural input markets more responsive to domestic demand, such that farms could bid more effectively for inputs by offering higher prices. Allocative efficiency, and the agricultural economy in general, would also benefit from a more effective farm credit system that could provide farms with working capital. Another way to strengthen allocative efficiency would be to improve the quality of farm management, especially with respect to economic decisionmaking. Russian grain producers, and the agricultural economy in general, would also benefit if the high internal transport and transaction costs of moving grain were lowered.

4. Conclusion

The results show that when assessed with respect to domestic prices, Russia in both 1990 and 2000 underused mineral fertilizer in the production of grain, from the point of view of both

allocative efficiency and farms' profit maximization. Using the most credible values for marginal productivity from the available empirical evidence, we find that from the point of view of trade prices, Russia in 1990 was overusing fertilizer, and in 2000 was very close to its optimal level of fertilizer use. These results help explain why during transition Russian use of fertilizer has plummeted while the country has exported the bulk of its fertilizer output.

5. References

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