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Productivity Effect of Urea Deep Placement Technology: An Empirical Analysis from Irrigation Rice Farmers in the Northern Region of Ghana

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***Abstract*—**This study examined the effect of Urea Deep Placement (UDP) technology on the output of irrigated rice farmers in the northern region of Ghana. Multi-stage sampling technique was used to select 142 rice farmers from the Golinga and Bontanga irrigation schemes, around Tamale. A treatment effect model was estimated at two stages; firstly, to determine the factors that influenced farmers' decision to adopt the UDP technology and secondly, to determine the effect of the adoption of the UDP technology on the output of rice farmers. The significant variables that influenced rice farmers' adoption of the UPD technology were sex of the farmer, land ownership, off-farm activity, extension service, farmer group participation and training. The results also revealed that farm size and the adoption of UDP technology significantly influenced the output of rice farmers in the northern region of Ghana. In addition to the potential of the technology to improve yields, it also presents an employment opportunity for women and youth, who are engaged in the deep placement of Urea Super Granules (USG), as well as in the transplantation of rice. It is recommended that the government of Ghana work closely with the IFDC to embed the UDP technology in the national agricultural programmes and policies. The study also recommends an effective collaboration between the government, through the Ministry of Food and Agriculture (MoFA) and the International Fertilizer Development Center (IFDC) to train agricultural extension agents on UDP technology in the rice producing areas of the country.

***Keywords*—**Northern Ghana, output, irrigation rice farmers, treatment effect model, urea deep placement.

I. Introduction

AGRICULTURE, led primarily by Ghana's smallholder subsistence farmers, has been the backbone of Ghana's economy in the entire post-independence history [15], and continues to contribute substantially to the country's GDP [10]. Agriculture contributed about 40% to Ghana's GDP in the late 1990s and was still above 35% until 2007. In the recent years of 2012 and 2013, the share of agriculture fell to below 30% to about 23% and 22%, respectively, and further fell to 21.5% in 2014 [10].

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In Ghana, rice is the second most important crop after maize and is fast becoming a cash crop for many farmers [16], [23]. National agricultural development plans and strategies, such as the Ghana Poverty Reduction Strategy (GPRS I), Growth and Poverty Reduction Strategy (GPRS II), Food and Agricultural Sector Development Policy (FASDEP) I and II, Medium Term Agriculture Sector Investment Plan (METASIP) I and METASIP II, which is on its way, have all considered rice as one of the targeted food security crops [24]. It is therefore not surprising that the Feed the Future USAID Ghana interventions such as Agricultural Development and Value Chain Enhancement (ADVANCE I & II), and the Agriculture Technology Transfer project (ATT), have featured rice as one of the target crops too. Annual per capita consumption of rice has grown rapidly, from 17.5 kg in 1999–2001 to about 24 kg in 2010–2011[19]. The demand for rice is projected to grow at a rate of 11.8% annually in the medium term [24], [16].

The value of rice imports in Ghana is about US$639.40 million annually [17]. This could put much pressure on Ghana's foreign currency reserves and food security. Reference [4] also reported that imported rice represents up to 70% of the total quantity of rice consumed in Ghana, translating to some 174% import penetration ratio.

The majority of the local rice production comes from the Northern (37%), and Upper East (27%) regions. Agricultural production in the Northern and Upper East regions declined in 2011 due to poor weather conditions. In general, rice production and the area cropped with rice are increasing [24]. Since 2007, the output of crops has been increasing at a faster rate compared with area under cultivation, indicating that yield during this period has been trending upward. The encouraging growth may be attributed to the various initiatives to develop the rice sector in Ghana, including the adoption of the National Rice Development Strategy (NRDS) in 2009; various donor-funded projects such as the Feed the Future Interventions and the Rice Sector Support Project (RSSP), and the National Fertilizer Subsidy Programme introduced in 2008. There was a jump in the production and acreage starting in 2008, which could be an accumulated effect of these initiatives. However, the national average yield of rice has remained comparatively low at about 2.5 MT/ha per year [17]. A recent survey by the Crops Research Institute (CRI) of Ghana, Savannah Agricultural Research Institute (SARI), Tamale, and the International Food Policy Research Institute (IFPRI), found a relatively lower yield (2.2MT/ha per season)

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than MoFA [24]. This presents a significant opportunity to achieve the potential yields of 6–8MT/ha.

Reference [24] noted that low adoption of inputs and improved technologies were the major reasons for this gap. The significant yield potential can be achieved through improvements in good agricultural practices and the adoption of underutilized beneficial agricultural technologies such as UDP technology which improves the efficiency in the use of nitrogen by the rice plants. This paper therefore employs a socio-economic approach to analyze the factors that influenced rice farmers' adoption of the UDP technology, and also the effect of the adoption of the UDP technology on the output of rice in Northern Ghana.

A. The UDP Technology

The UDP technology was developed by the International Fertilizer Development Centre (IFDC) having worked with farmers for over two decades, particularly in Bangladesh [25], "undated" [13]. The main goal of the UDP technology is to improve nitrogen use efficiency in rice production which is expected to improve output. UDP technology is made up of two key components. First, is a fertilizer 'briquette' produced by compacting prilled urea fertilizer into Urea Super Granules or USG that weighs about 1-3 grams per briquette. The second key component of the UDP technology is the placement of USG below the soil surface at the root zone of the plant. The briquettes are centred between four rice plants at a spacing of 20cm x 20cm and at a depth of between 7cm and 10cm. It is applied within 7-10 days after transplanting. Placement can be done either by hand or with a mechanical applicator. The briquette releases nitrogen gradually, meeting with the crop's requirements during the growing season "undated" [13]. Also, in this production process N fertilizer is required to be applied only once for the entire crop season unlike conventional urea production process when 1-2 split applications are required (mainly broadcasting first and then top-dressing subsequently) in Ghana.

II. Materials and Methods

A. Study Areas: Background of the Bontanga and Golinga Irrigation Schemes

The Bontanga Irrigation Project is a large-scale gravity-fed scheme, and the largest in the Northern Region of Ghana [6]. It is located at Bontanga in the Kumbungu District of Ghana, 34 km North West of Tamale, the regional capital of the Northern Region of Ghana. The scheme covers a potential area of 800 hectares. However, only about 450 hectares is considered irrigable, of which 240 hectares is used for rice cultivation and the remaining 210 hectares for upland vegetables production [6]. Presently, 13 communities (Tibung, Kumbungu, Kpalsogu, Dalun, Wuba, Kukuo, Kpong, Saakuba, Yipelgu, Voggu, Kushibo, Zangbalung and Gbugli) are using the Bontanga Irrigation Project area [1]. The farmers' population on the project as of 2012 was 525 and they were organised into a cooperative comprising 10 farmers-based organisations (FBOs) [6]. The average farm size on the project is 0.6 hectare. The main crops cultivated within the project area include rice, maize, onion, pepper, tomato and okra [27], [18].

The Golinga Irrigation Project is a medium-scale gravity-fed scheme located at Golinga in the Tolon District, Northern Region of Ghana [18]. The project is fed by the Kornin River. The scheme has a potential of 100 hectares of which 40 hectares is cropped. The vegetables are produced only in the dry season from October to April, while rice is produced both in the dry and wet seasons. Five communities (Golinga, Gbulahigu, Tunaayili, Galinkpegu and Naha) are sharing the Golinga Irrigation Project's area. In 2012, 150 farmers organised into a cooperative made up of five FBOs used the scheme [6]. The average farm size on the project is 0.2 hectare. The farmers on this project cultivate the same crops as those on the Bontanga irrigation scheme.

B. Sampling Techniques and Data Collection

The study used multi-stage sampling technique. In the first stage, purposive sampling techniques were used to select the Bontanga and Golinga irrigation schemes because of their superiority and popularity in rice production under irrigated conditions in Northern Ghana. In the second stage, stratified sampling was used to form two groups of farmers-UDP adopters and Non UDP adopters. Simple random sampling was then applied to select 142 farmers (71 adopters, and 71 non adopters) for the study. Fifty farmers were selected from Golinga, and 92 from the Bontanga irrigation scheme. Primary data were then collected using a scientifically designed questionnaire through face-to-face interviews with the farmers.

C. Analytical Framework

The study used the treatment effect model for analysing the data. This was estimated at two stages. First, to examine the factors influencing farmers' decision to adopt the UDP technology, and secondly, to determine the effect of the adoption of the UDP technology among other variables, on the output of irrigated rice farmers in the Bontanga and Golinga irrigation schemes in the Northern Region of Ghana.

D. Theoretical Model Specification - Treatment Effect Model

The Treatment effect model is one form of the Heckman two stages approach for correcting selectivity bias. This has been used extensively in evaluating programmes since the selection criteria for observations in such studies are non-random. The main aim of this study was to determine the effect of the adoption of UDP technology on the output level of farmers. By implication, we were not only interested in correcting selectivity bias but also, measuring the real effect of the UDP technology on the output of irrigated rice farmers. Consequently, the treatment effect model was adopted. Just like the Heckman two stages approach, the treatment effect model estimates the selection equation in the first stage to obtain the predicted values of the selection variable (adoption of UDP technology), which is then used to generate an Inverse Mills Ratio (IMR) also known as *lambda*. Both the predicted values of the selection variable and the IMR are then added to the outcome equation in the second stage as an additional variable. Mathematically,

$$Y = X_i'\beta + \delta A_i + u_{1i} \tag{1}$$

where Y is output of rice, X_i' are exogenous variables that influence rice output, A_i is adoption of UDP technology, which takes the value 1 if a farmer adopted and (0) if otherwise. u_i is a two sided error term with $N(0,\sigma_v^2)$. β and δ are parameters to be estimated.

From [14], this may not provide an adequate result since A_i is endogenous. Therefore, a selection equation of A_i is first estimated as:

$$A_i^* = Z_i'\gamma + u_{2i} \tag{2}$$

where Z_i' is a set of exogenous variables that influence the selection variable A_i, γ is a parameter to be estimated and u_2 is also a two-sided error term with $N(0,\sigma_v^2)$.

Note that we cannot simply estimate the substantive equation (without first estimating the selection equation) because the decision to adopt may be influenced by unobservable variables like innovativeness that may also influence rice output. This implies that the two error terms (in the selection and substantive equations) are correlated, leading to biased estimates of β and δ.

If we assume that u_{1i} and u_{2i} have a joint normal distribution with the form:

$$\left[\frac{u_{1i}}{u_{2i}}\right] \sim N\left(\begin{bmatrix}0\\0\end{bmatrix}, \begin{bmatrix}1 & \rho\\ \rho & \sigma^2\end{bmatrix}\right), \tag{3}$$

Then it follows that the expected output of those who adopted UDP is given as:

$$\begin{aligned} E[X_i \mid C_i = 1] &= Z_i\beta + \delta + E[u_{2i} \mid C_i = 1] \\ &= Z_i\beta + \delta + \rho\sigma\lambda_i \end{aligned} \tag{4}$$

where

$$\lambda_i = \frac{\phi(-Z_i'\gamma)}{1-\Phi(-Z_i'\gamma)} \text{ is the IMR} \tag{5}$$

Equation (4) implies that when we estimate (2) without the IMR, the coefficients β and δ will be biased.

According to [14], when output of both adopting farmers and non-adopting farmers are considered then (1) takes the form;

$$Y_i = \beta'(\Phi_i X_i) + \delta'(\Phi_i C_i) + \sigma\phi_i + e_{2i}$$

where

$$\Phi_i \equiv \Phi(z_i'\gamma) \tag{6}$$

E. Empirical Models Specification

Following the above theoretical model, the empirical models that were estimated to determine the factors influencing farmers' decision to adopt UDP and the effect on rice output are as follows:

$$\begin{aligned} Adoption\ of\ UDP = \delta_0 + \delta_1 Sex + \delta_2 Experience \\ + \delta_3 Land\ ownership + \delta_4 Off\ farm \\ + \delta_5 Extension + \delta_6 Farmer\ group \\ + \delta_7 Credit + \delta_8 Attended\ training + \delta_9 Age \\ + u_2 \end{aligned}$$

In the second stage:

$$\begin{aligned} Output\ (rice) = \beta_0 + \beta_1 Farm\ size + \beta_2 labour + \beta_3 Weedicides \\ + \beta_4 Prilled\ urea + \beta_5 Seed \\ + \beta_6 Adoption\ of\ UDP + u_1 \end{aligned}$$

The definitions and the *a priori* expectations of the variables are indicated in Table I.

TABLE I
DEFINITION OF VARIABLES

Variable	Definition	Expected sign
Sex	Dummy (1 for male, 0 for female)	+
Experience	The number of years a farmer had been cultivating rice	+
Land ownership	Indicates whether the farmer's plot is rented or self-owned	+
Off-farm income	Dummy (1 for a farmer who had other sources of income, 0 if otherwise)	+
Extension service	The number of times a farmer received extension service in a year	-/+
Farmer group	Dummy (1 for if the farmer belonged to an FBO, 0 if otherwise)	+
Credit	Amount of agriculture credit in GHC received by the farmer	+
Attended training	Dummy variable (1 for farmers who attended UDP trainings, 0 if otherwise)	+
Age	How old the farmer was (in years)	+
Output of rice	Natural log of output (where output is the total output of rice in kg for the cropping season)	+
Farm size	Natural log of total farm size in acreage for irrigated rice	+
Labour	Natural log of labour (measured in number of farm hands)	+
Weedicide	Natural log of quantity of weedicide used (measured in number of litres used)	+
Prilled urea	Quantity of Prilled urea used in kg	+/-
Seed	Natural log of seed (measured in quantity of seed used in kg)	+/-
UDP	Dummy variable (1 for UDP technology adopter, 0 if otherwise)	+

III. RESULTS AND DISCUSSION

A. Determinants of the Adoption of the UDP Technology by Rice Farmers

To determine the effects of the adoption of UDP technology on the output of rice, a treatment effect model was estimated at two stages. The dependent variable in the first stage

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(Treatment or Probit equation) was rice farmers' UPD technology adoption constraint (see Table II).

The likelihood-ratio test of 104.28 was highly significant at 1%, indicating that we can reject the null hypothesis of no correlation between the treatment errors and the outcome errors. This supports the choice of the treatment effect model to correct for selection bias. The significant covariates that influenced rice farmers' adoption of the UPD technology were: sex of the farmer, land ownership, off-farm activity or income, extension service, farmer group participation, and attending UDP trainings.

Sex was positive and significant at 5%. This meant that male farmers had a higher probability of adopting the UDP technology than their female counterparts. This finding conformed to our a priori expectation. The finding could be attributed to the socio-cultural setting in the Northern part of Ghana where ownership of productive resources, especially agricultural land for production purposes, is male dominated. These lands are mostly handed to male children as inheritance from their parents, with the belief that females would be married out to other families. Agricultural land in Northern Ghana is predominantly owned by men, with women providing some form of family labour to support household production. This finding corroborates with [2] who found that gender was positively related to the number of technologies adopted by farmers in their production efforts. They established that male farmers in Northern Ghana had a higher propensity to adopt soil and water conservation techniques than females. They argued that adoption of these techniques were laborious and needed resources which typically are owned by men.

Land ownership was also positive and significant at 1%, meeting our a priori expectation. Farmers who owned lands on which they cultivated had a higher propensity (0.468) to adopt the UPD technology than those who produced rice on rented lands. This was plausible, because those who owned their lands could permanently improve upon the fertility without the fear of losing them to another person, as it could sometimes be with the case of rented lands. Apart from the self interest in developing their own lands, there was also the element of security that the land belonged eternally to them. This finding disagreed with [8] who found farmers who cropped on rented land adopting more technologies than those who owned their farm lands. Reference [7] found that women who rented their farm plots in Nigeria did not make significant participation in farm management decisions making. Similarly, in [9], farmers who owned their plots had greater probability of adopting more technologies than their counterparts who were land tenants. Like [9], some academics have opined that it is normally when the investments on their farms are permanent that land owners are willing to undertake.

Farmers who participated in other off-farm income earning activities were also found to adopt the UDP technology more. This variable was positive and highly significant at 1%. It was possible that those farmers made more money from their off-farm ventures which they tend to invest in their rice farms. The availability of the financial resource thereby increased their propensity to expend more on adopting the UDP technology, which comes with a set of protocols including transplanting in rows and the usage of improved seed that have financial implications.

As observed by this study, the greater number of visits that a rice farmer received from an agricultural extension staff, the less the probability of that farmer to adopt the UPD technology. This had a marginal effect of about -0.43. This finding was consistent with our a priori expectation. The UDP technology was relatively new in Ghana, introduced by the International Fertilizer Development Centre (IFDC) through the ATT project in the Savannah Accelerated Development Authority (SADA) intervention zone of Northern Ghana. Extension staff of MoFA and for that matter, the Ghana Irrigation Development Authority (GIDA) did not have technical expertise on this technology to be able to communicate to the rice farmers. Information communicated to rice farmers by extension agents on rice production methods was most likely going to be deficient in UDP technology. Reference [8], [9], found this variable to be positive and significant. They observed that the uptake of a new technology was facilitated by the farmers' contact with extension staff, since extension officers provided technical backstopping. Reference [26], also found that extension services significantly influenced the adoption of improved maize varieties in the hills of Nepal. These findings are plausible only if the extension agents were communicating the right information to farmers.

Group membership was also found to be highly significant at 1% and had a positive influence on the adoption of UDP technology. This implied that farmers who belonged to a farmer group had greater probability (about 0.856) of adopting more than those who did not. There was the likelihood of group influence on individual farmers as the procurement of technologies and inputs for farming was going to be done by the leadership for all group members.

Finally, farmers who attended trainings on the UDP technology had a greater probability (about 0.858) of adopting the technology than their untrained counterparts. The UDP technology was new for rice farmers. Farmers therefore needed to be trained on its protocols and application processes in order for them to be efficient and effective in its usage. These trainings were mostly led by trained staff of IFDC, through famer-led demonstrations and learning centres. Many empirical findings including those of [8], argued that training is an added input which embraces good performance and adoption. They further stated that the benefits of training included acquiring new knowledge, skills or attitudes being transferred to farmers. In their study also, [3] found that a farmer's participation in on-farm tests, as well as the number of times farmers attended workshops and fora, influenced positively their adoption of new agricultural technologies and good farm practices in Burkina Faso and Guinea.

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TABLE II
DETERMINANTS OF ADOPTION OF UDP TECHNOLOGY (PROBIT)

Variable	Coef.	Marginal effect	dy/dx Std. Err.	P>lZl	dy/dx P>lZl
Sex	1.7380	0.5440**	0.2581	0.025	0.035
Experience	-0.0273	-0.0055	0.0064	0.401	0.384
Land ownership	1.9220	0.4684***	0.1369	0.000	0.001
Off-farm income	1.5653	0.2149***	0.0737	0.017	0.004
Extension	-2.2908	-0.4343***	0.1086	0.002	0.000
Farmer group	3.0844	0.8557***	0.1119	0.000	0.000
Credit	0.0013	0.0003	0.0002	0.243	0.243
attending training	3.0355	0.8575***	0.0828	0.000	0.000
Age	-0.0272	-0.0055	0.0058	0.328	0.339
Cons.	-3.9030***			0.005	

Likelihood Ratio test of indep. eqn: Chi^2 = 104.38, Prob>Chi^2 = 0.0000, Pseudo R^2 =0.5938.

Source: Authors' estimation using STATA, 2016.

Note: **= significant at 5%, and ***= significant at 1%.

B. Determinants of Rice Output in Northern Ghana

This section discusses the second stage results of the treatment effect model (see Table III). The Wald test is highly significant at 1%, indicating a good model fit. This implies also that there was significant correlation between the treatment errors and the outcome errors, supporting the choice of a selection model to correct for bias. The estimated correlation between the treatment-assignment errors and the outcome errors is -0.0633, indicating that unobservables that raise observed output of rice tend to occur with unobservables that lower the adoption of the UDP technology. Only two covariates (farm size and the adoption of UDP) were statistically significant and positively influenced the yields of rice farmers.

The adoption of the UDP technology was found to be significant at 5% and positively influenced the output of rice. The coefficient indicates that farmers who adopted the UDP technology had higher output (about 21.5%) than the non-adopters. This finding is consistent with [5], who suggested that Fertilizer Deep Placement (FDP) can be used by farmers to improve nitrogen use efficiency and increase grain yields in the irrigated rice cropping system. They further added that FDP was a promising technology that could be adopted by African rice farmers, particularly for those under irrigated schemes. In Bangladesh, yields of rice were increased by 15-25%, while expenditure on commercial fertilizer was decreased by between 24-32% when fertilizer briquettes were used as the source of plant nutrients [12]. Other studies conducted across the world, including those by [11], [21], also showed significantly, the superiority of UDP technology over the use of prilled urea. As reported earlier, the UDP technology was a package of good farming practices for rice production including deep placing of the urea briquettes at the root zone of the rice plant to reduce nutrient loss. Aside the productivity and economic benefits of the UDP, the technology is also noted to have environmental benefits because deep placing the fertilizer reduces chemical leakage and contamination in running waters. There is also the possibility of reducing the greenhouse effect. The UDP package also include the use of improved seed, row transplanting and proper levelling and puddling of the fields to ensure even distribution of water on the rice farm. According to Ghana's Agricultural Policy Document, METASIP [20], a major reason for the non-attainment of achievable yields for cereals was low soil fertility, which was partly due to low usage of fertilizers. Most soils, especially those of the Northern parts of Ghana have depleted resulting in low nutrient levels.

Farm size was found to be positive and significant at 1%. The results revealed that a 100% increase in the farm size resulted in about 56% in the output of the rice farmers. This could possibly be true due to economies of scale, and also because the farmers have become knowledgeable in the application of the UDP technology. Reference [22], analysed the factors affecting rice output among Agricultural Development Programme (ADP) contact farmers in the mining and non-mining locations of IVO LGA of Ebonyi State, Nigeria. His study also found that farm size positively and significantly influence the output of rice farmers.

The non-significant covariates include labour, weedicides, prilled urea, and the use of local or farmer saved seed. The use of improved seed varieties was still a problem among rice farmers in Northern Ghana, as most farmers used their own saved seeds (grains). In their study on the patterns of adoption of rice technologies in Ghana, [24] found that only 34% of rice area was planted with modern varieties, while 24% was planted with seed sourced from other farmers or from the grain market. Moreover, only 16% of rice area was planted with freshly acquired certified seed in 2012. Farmers recycle their modern rice seed varieties for four to five years on average.

TABLE III
DETERMINANTS OF OUTPUT OF RICE

Variable	Coefficient	Std. Err.	P>lZl
Farm size	0.5616***	0.0538	0
Labour	0.0265	0.0465	0.569
Weedicides	0.0999	0.0686	0.145
Prilled urea	0.027	0.0822	0.743
Seed	0.0399	0.0285	0.162
Adoption of UDP	0.2148**	0.088	0.015
Cons.	2.6115	0.1133	0
Hazard lambda	-0.0192	0.0736	0.794
Wald Chi^2 = 295.76, Prob > Chi^2 = 0.0000			
rho	-0.0633		
sigma	0.3039		

Source: Authors' estimation using STATA, 2016.

Note: **= significant at 5%, and ***= significant at 1%.

IV. CONCLUSION AND POLICY IMPLICATION

This study sought to determine the factors that influenced farmers' decision to adopt the UDP technology, and to determine the effect of the adoption of the UDP technology on the output levels of irrigated rice farmers in the northern region of Ghana. The study concludes that the sex of the farmer, land ownership, off-farm activity, extension service, farmer's group membership and attending trainings

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significantly influence farmers' decision to adopt UDP technology. The study also concludes that farm size and the adoption of UDP technology significantly influenced the output of rice farmers in the northern region of Ghana. The importance of farmers getting access to the right quantities of farm inputs, as well as improved agricultural technologies is validated by this study. As a matter of national policy as in the case of Bangladesh, the government of Ghana should work closely with IFDC to embed the UDP technology in the national agricultural programmes and policy documents. The UDP technology does not only have the potential to improve yields but also presents employment opportunity for women and the youth who will be engaged in the deep placement exercise as well as in the transplantation of rice. There should be an effective collaboration between the government, through the Ministry of Food and Agriculture (MoFA) and IFDC to train agricultural extension Agents on the UDP technology in the rice producing areas of the country.

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