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Abstract

Quality control in fertilizer markets is critical to food security by facilitating fertilizer application and increasing agricultural productivity. With the active proliferation of new fertilizer producers, Vietnam has also faced this problem, but public and market initiatives have recently been taken to address the issue This paper evaluates the quality of 141 randomly sampled fertilizers in the Mekong Delta, the country's central rice producing area. We intentionally sampled unbranded products to focus on the most vulnerable market segment. On average, our sample contains the labeled nutrient content. However, the quality variability is high, and half of the sample has at least one nutrient content below the legal requirement. We also find that nitrogen is over-concentrated and phosphate is diluted. These findings suggest that the quality of fertilizers in Vietnam, even unbranded ones, is reliable on average, but efforts are needed to stabilize quality variability. In addition, over-concentration of nitrogen may warrant policy attention as farmers may inadvertently over-apply nitrogen and harm the environment.

Keywords: low-quality fertilizer, experience goods, Vietnam
JEL codes: L15, L51, Q16, Q18,

1. Introduction

Fertilizers are essential for improving agricultural productivity and food security (Evenson and Gollin, 2003; Foster and Rosenzweig, 2010; Njeru et al., 2016). However, many developing countries face the prevalence of low-quality fertilizers in the market or farmers' (mis)perceptions about them. These concerns inhibit the use of fertilizers, thereby, hampering farm productivity and profitability.[1] Recent studies on fertilizer quality, focusing on sub-Saharan Africa (SSA), show that farmers often underapply fertilizer because they believe it to be of poor quality with low returns (Ashour et al., 2018; Ariga et al., 2019; Bold et al., 2017; Hoel et al., 2021; Michelson et al., 2021; Ola and Menapace, 2020). Quality control in fertilizer markets is critical for promoting agricultural development, ensuring a stable food supply, and improving the welfare of agrarian economies. However, effective countermeasures are poorly understood, and practical policies are not well established in developing countries. It is important to assess the fertilizer quality in a context where initiatives have been taken to address the problem.

This study analyzes fertilizer quality in Vietnam, one of the world's largest rice-producing and exporting countries, which has recently developed public and market initiatives to address fertilizer quality issues (Kojin et al. 2023). We purchased 141 fertilizers from randomly selected fertilizer retailers in the Mekong Delta region, Vietnam's main rice production area. Our focus is on unbranded products, where the risk of low quality fertilizer penetration is high. We compared the actual levels of three key nutrients - nitrogen, phosphate, and potassium - with the levels declared on the labels. We also conducted in-depth interviews and discussions with stakeholders, including government officials, fertilizer retailers, and farmers, to learn about fertilizer governance, production, distribution, and use.

We find that the average nutrient content of our sample fertilizers, for each nutrient, is close to the level indicated on the labels. However, the variability in quality is large. Half of the samples did not meet the regulatory requirements for at least one nutrient. In particular, 6% of the samples were missing the total of the three key nutrients by more than 10%, the legally acceptable level,

[1] Other important barriers to fertilizer adoption include lack of knowledge and information, credit constraints, costs, uncertain or lower than expected returns, and behavioral constraints. See Foster and Rosenzweig (2010), Magruder (2018), and Macours (2019) for recent reviews of technology adoption, including fertilizers in agriculture, and Jayne et al. (2018) and Holden (2019) for critical reviews of fertilizer subsidies to promote adoption. Khor et al. (2018) identify risk aversion to reduced fertilizer use among low-income farmers in Vietnam.

and had each key nutrient below the level indicated on the level, making them susceptible to intentional adulteration or mislabeling. Moreover, many samples suffer from variations in nutrient *composition*: fertilizers have too much of some nutrients and too little of others. Fertilizer price is positively correlated with its quality, but the relationship is weak, suggesting that fertilizer quality is difficult to assess from price.

We attempt to determine why the nutrient composition varies within a sample. One possibility is that granules are not stirred enough. We investigate this by comparing mixed and complex fertilizers. Mixed fertilizers blend three granules of straight fertilizer for each nutrient, while complex fertilizers contain all three nutrients in a single granule. Thus, mixed fertilizers are more susceptible to greater nutrient variations. We find that the nutrient content of mixed fertilizers is more variable than that of complex fertilizers, and that nitrogen appears to mask the lack of phosphate. Although inconclusive, the evidence is consistent with unintentional compositional variation due to poor mixing or technical failure. We also discuss the possibility of intentional variation by producers to substitute cheap nutrients with expensive ones.

These results suggest that for the unbranded fertilizers in the Mekong Delta, the labels are (on average) reliable, but that we cannot rule out the possibility of simple adulteration by foreign matter contamination or mislabeling. Farmers face a half chance of buying a product that is substandard in at least one nutrient content, and the products often contain both over-concentrated and diluted nutrients. The findings suggest the importance of technological upgrading to stabilize quality.

Vietnam is an appropriate case to study fertilizer quality issues because it is a step ahead of SSA in terms of agricultural development and governance of fertilizer quality. Rice yields in Vietnam tripled between 1980 and 2020, in part due to intensified fertilizer use, with nitrogen inputs increasing 20-fold (Section 2.2), despite a history of low fertilizer quality (Kojin et al., 2023, Table 1; Nguyen, 2017). Vietnam meets several criteria for the late stage of fertilizer market development (Ariga et al., 2019). Kojin et al. (2023) detail the governance of fertilizer quality in Vietnam, where large networks of fertilizer producers and agro-dealers have emerged in the market under the control of current government policies and regulations. In addition, branded products are well established in the Vietnamese fertilizer market, unlike in SSA, where farmers do not pay much attention to brands. Therefore, the current status of fertilizer quality in the Vietnamese market provides useful information for examining and discussing the effectiveness of such government and market initiatives.

This paper contributes to the growing literature on fertilizer (and agricultural input) quality (Ashour et al., 2019; Ariga et al., 2019; Bold et al., 2017; Michelson et al., 2021; Ola and Menapace, 2020). Key questions are the extent of fertilizer quality, the ability and accuracy of farmers to infer the quality from market signals and observable characteristics, and how and why low-quality fertilizers or farmers' (mis)perceptions persist. Most studies examine the case of SSA, where both public and private initiatives to eliminate low-quality fertilizer are weak. We add to the literature by estimating the prevalence of low-quality fertilizer in an Asian agricultural economy with efforts to regulate fertilizer quality in the market. We complement a detailed comprehensive description of the public and market initiatives to regulate fertilizer quality in Vietnam (Kojin et al. 2023) by providing objective scientific evidence on fertilizer quality in the markets.

We also contribute to the literature by proposing an idea for investigating whether the quality deviations are caused by technical defects. Identifying whether the problem is an unintentional technical problem is important because intentional quality dilution requires different policy interventions such as regulation and inspection, whereas unintentional quality problems due to inadequate knowledge or technological defects may require technical training and support.

The remainder of this paper is organized as follows. Section 2 presents the conceptual framework of the fertilizer quality problem and the background of the fertilizer market in Vietnam. Section 3 explains the data. Section 4 describes the test results of fertilizer quality in the market. Section 5 summarizes the results and discusses their implications.

2. Conceptual framework and background

2.1. Fertilizers as "noisy" experience goods

We consider a fertilizer to be *low quality* if its nutrient content is below the level indicated on the label and *substandard* if the content is below −10% of the level indicated on the label, which is the legal lower limit as defined by Decree 108 (108/2017/NĐ-CP) in Vietnam. The production of low-quality fertilizers may be intentional, when producers try to increase their profits by using inappropriate ingredients or mixing in contaminants or additives. Technical deficiencies such as inadequate technology, poor quality control, insufficient chemical knowledge, or improper storage or transportation could also be a reason for low-quality fertilizers.[2]

Reputation mechanisms typically resolve adverse selection by removing lemons from the market; consumers continue to buy a product until they discover that it is of low quality, and producers or suppliers ensure the supply of high-quality products to maintain loyal consumers (i.e., reputation) (MacLeod, 2007). However, reputation mechanisms may not work for fertilizers because consumers cannot accurately assess the product quality but only observe its noisy signals (e.g., crop growth), which are also influenced by other factors (e.g., soil nutrients, weather conditions, and farming practices) (Bold et al., 2017).[3] As a result, low-quality fertilizers may dominate the market, and farmers may find it difficult to apply the optimal amount of fertilizer or be discouraged from applying fertilizers.

2.2. Agricultural production, fertilizer use, and governance in Vietnam

Agricultural production in Vietnam has expanded since the transition from a central planning to a socialist-oriented market economy, facilitated by the economic reforms known as *doi moi* in 1986. Rice production exceeded the policy targets after the start of *doi moi*, and Vietnam became the world's fifth-largest rice producer and the third-largest exporter in 2018 (Food and Agriculture Organization of United Nations, 2023). Our study area, the Mekong Delta, is the largest rice bowl, followed by the Red River Delta. The increase in rice production and yield in the early *doi moi* period was driven by improved farmer motivation to produce rice and technological improvements, such as the construction and maintenance of irrigation facilities, the adoption of modern varieties, and a rapid increase in fertilizer application.

Fertilizer production has responded to the increase in its demand (Kojin et al, 2023). Although the supply of DAP (i.e., diammonium phosphate) is still dependent on imports, the domestic supply of NPK (fertilizers containing nitrogen (N), phosphate (P), and potassium (K)), urea, and phosphate, which accounts for about 70% of fertilizer demand in Vietnam, exceeds domestic use (Bùi, 2019: 18-19; Vũ, 2018).[4]

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[2] The concept of substandard/spurious/falsely labeled/falsified/counterfeit (SSFFC) proposed by WHO (2011) for medical products is useful and comprehensive to address the problem.

[3] This is a common problem with noisy experience goods like seeds, pesticides, herbicides (Ashour et al., 2019), or anti-malaria drugs (Björkman Nyqvist et al., 2022).

[4] Large state-owned enterprises belonging to either the Vietnam National Chemical Group (VINACHEM) or the Vietnam Oil and Gas Group (PVN) and four other large enterprises account

Figure 1 presents the fertilizer distribution channels in Vietnam, with the main channel indicated by a bold arrow, based on our interviews.[5] The main intermediary channels of the large-scale enterprises are agents (*đại lý*) with sufficient capital and retailers (*cửa 6ang*). Distributors (*nhà phân phối*) are another intermediary channel between large enterprises and agents or retailers.[6] In addition, there are few other channels: direct sales from large enterprises to farmers (who are often involved in contract farming or are large farmers) and distribution through cooperatives. Small producers include emerging companies that are new to the business and are more likely to produce fertilizers of lower quality or more unstable nutrient composition due to inadequate skills and technologies. They market their fertilizers through similar channels as large producers and also through direct sales to farmers, which is a less regulated market channel. The exact share of each channel is unknown due to a lack of data. However, all our informants agreed that the channel indicated by the bold arrow is the main one.[7]

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for approximately 95% of the total fertilizer production in Vietnam (Vũ, 2018). VINACHEM includes Habac Nitrogenous Fertilizer & Chemicals Company Ltd., Binh Dien Fertilizer Joint Stock Company, Ninh Binh Nitrogenous Fertilizer Ltd. Company, Southern Fertilizer Corporation, Van Dien Phosphate Corporation, Lam Thao Phosphate and Chemical JSC, Ninh Binh Phosphate Fertilizer Joint Stock Company, Can Tho Fertilizer & Chemical Joint Stock Company, DAP-VINACHEM Joint Stock Company, and DAP2-VINACHEM Joint Stock Company. The PVN Group consists of PETROVIETNAM Fertilizer and Chemicals Corporation, and PETROVIETNAM Ca Mau Fertilizer Joint Stock Company. The other four large companies are Five Star International Group, General Materials Biochemistry Fertilizer Joint Stock Company, Banconco Group, and Japan Vietnam Fertilizer Company. Along with these major producers, we also excluded major unlisted companies reported in FPT Securities (2015): Quang Binh Import & Export JSC, Que Lam Group, Agricultural Products, and Materials JSC (Apromaco), Song Gianh Corporation, and Thien Sinh JSC.

[5] We conducted interviews with fertilizer manufacturers, government officials, fertilizer retailers and wholesalers, large-scale producers, farmers, cooperatives, and specialists in soil science and fertilizers in provinces in the Mekong Delta and Hanoi, in August 2018 and August 2019. Retailers and farmers were introduced by local government officials following the standard academic survey protocols in Vietnam.

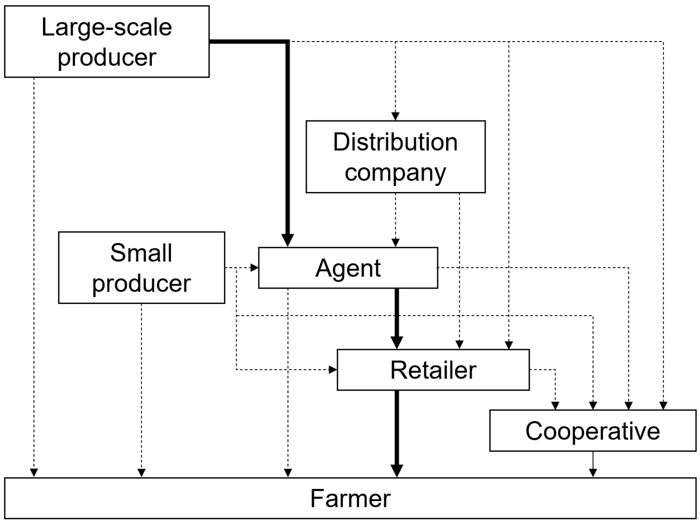
[6] Ihara (2020) details the intermediary channels of Vietnamese toiletries and indicates that distributors are identified as warehousing and customer service providers in the relatively broad market while retaining ownership of products. Agents are identified as entities selling products on behalf of suppliers or distributors without physical possession of the products. This classification could be adapted to fertilizer distribution, although there may be minor differences across products.

[7] The distribution channel of imported fertilizers is not well known, even among government officials, fertilizer wholesalers and retailers, and other experts we interviewed. However, it is

Figure 1. Fertilizer distribution channels in Vietnam

Source: Prepared by the authors based on the August 2018 interview survey.

Note: The bold arrow represents the main channel.



A comprehensive review of the media reports by Kojin et al. (2023) suggests that substandard fertilizers have been on the market for over a decade. Violations include missing ingredients, fake packaging of well-known brands, counterfeiting with silicone, and disguising the country of production. Proposed reasons for the production of substandard fertilizers include inadequate knowledge and technology of small-scale producers, collusion between producers and retailers, importation of low-quality/counterfeit fertilizers, corruption in the authorized organizations that conduct the fertilizer testing required for approval of distribution, insufficient penalties for production and distribution of substandard fertilizers, and cheap taste of farmers, especially in remote areas.

Low-quality fertilizers (mainly NPK) can have negative economic and environmental impacts. Nguyen (2017: 47) links low and unreliable quality to over-fertilization in Vietnam. Indeed, Vietnam is an intensive fertilizer user, ranking fourth among Asian countries in 2016 (Food and

likely to be distributed through the same channels as domestic products. According to newspaper reports, Chinese products account for approximately 50% of imported fertilizers (Minh, 2018).

Agriculture Organization of the United Nations, 2023). Using more fertilizer than recommended increases production costs and reduces profits (Nguyen, 2017: 41–43; Stuart et al., 2018; Tran et al., 2018). Overfertilization also causes soil pollution, such as soil fertility loss (Hà et al., 2018) and soil acidification (Crews and Peoples, 2004).

Given the prevalence of low-quality fertilizers, several initiatives are being taken to mitigate the problem. Kojin et al. (2023) report that government controls, including licensing, mandatory quality labeling, and random inspections, are being implemented. Market initiatives by producers through branding, warranty, and dealer certification can help build and maintain reputations and enable farmers to identify better quality products. Kojin et al. (2023) also report on a mechanism where poor quality goods are excluded through social-learning where farmers' learning and feedback to retailers help to update local retailers' product assortment.

3. Data

We focus on the retail channel (**Figure 1**), which has the largest share of all distribution channels. This channel has the potential to benefit the most from government initiatives targeting licensed fertilizer retailers (see Section 2.2). In contrast, farmer cooperatives and contract farming are relatively small channels and have innate internal incentives to distribute good quality fertilizer even without government initiatives.

We randomly selected two districts from each of the five major agricultural provinces (An Giang, Hậu Giang, Kiên Giang, Sóc Trăng, and Vĩnh Long) in the Mekong Delta.[8] We obtained a list of certified fertilizer retailers from each district government[9] and randomly sorted the listed retailers to determine the order of visits. Between November 2018 and April 2019, several local coauthors visited the sampled retailers using a mystery shopper approach to purchase 1 kg from 50 kg bags of either NPK or DAP after mixing the fertilizer in the bags (Bold et al., 2017; Michelson et al., 2021). Farmers typically purchase whole bags of fertilizer (typically 50 kg), but they can also purchase fertilizer in smaller portions.

In selecting the sample, we deliberately focused on unbranded products to increase the prior

[8] We excluded Can Tho city because it is exceptionally urbanized, regulations are strictly implemented, and the marketing system seems well organized.

[9] For Soc Trang province, we did not have access to the list of licensed fertilizer retailers. Therefore, we thus randomly selected ten communes (xã) and randomly visited two retailers for each commune.

probability of detecting low-quality fertilizers at each sample retailer. During our preliminary interviews, government officials, fertilizer manufacturers, retailers, and farmers indicated that branded fertilizers are most likely to meet quality standards because of regular inspections and manufacturers' warranties, but they are less certain about the quality of unbranded products. Therefore, at each sample retailer, we excluded major fertilizer brands and purchased the cheapest unbranded fertilizers available, which are often from small start-up producers. They may lack the knowledge and skills to produce proper fertilizers, or they may have a greater incentive to make short-term profits by supplying low-quality fertilizers. Note that our sampling strategy is consistent with the recent studies in SSA, where farmers typically purchase cheap unbranded fertilizers (Bold et al., 2017; Michelson et al., 2021).

If a retailer did not sell the fertilizer in small quantities (1 kg) or only sold major brands, we left the store and visited the next retailer on the list. We repeated this process until the sample size reached the target number of retailers, which is proportional to the total number of retailers in each district. The limitations of this sampling method are discussed in **Section 5.2**. The purchased fertilizer was double-sealed in a zip-lock bag after leaving the store. We also recorded the name of the retailer, the date and time of the visit, the labeled nutrient composition (e.g., 16-16-8), the manufacturer or brand name, and the retail price.

The sampled fertilizers were immediately delivered to the Laboratory of Soil Chemistry, Department of Social Science, Can Tho University, Vietnam. The nitrogen (N), phosphate (P), and potassium (K) contents of the sample fertilizers were measured,[10] and the results were

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[10] The laboratory used the following methods to measure each nutrient. N is the sum of urea, NH_4^+ and NO_3^-. To measure the content level of urea, the sample was extracted with HCl 0.05N at a ratio of 1:100, and then urea-N was determined by the colorimetric method on a spectrophotometer. For NH_4^+ and NO_3^-, the sample was extracted with HCl 0.05N at a ratio of 1:100, and then NH_4^+ and NO_3^- were determined by colorimetric method on spectrophotometer. To determine the content level of P, the sample was digested with mixture of concentrated HNO_3 + HCl (1:3) and then H_2SO_4 8M was added. P in the digested sample was determined by colorimetric method (molybdate blue method) on spectrophotometer. To measure K, the sample was digested with a mixture of concentrated HNO_3 + HCl (1:3), and then H_2SO_4 8M was added. K in the digested sample was determined on atomic absorption spectrometer. The standard series for the regression curve are prepared from standard chemicals to measure analytical error.

confirmed by double testing. The nutrient test results were matched with information from the retailer survey, resulting in 141 observations for our analysis.

Table 1 describes the nutrient composition of the sample fertilizers as indicated on the label, the sampling location, the price, and whether it was a complex fertilizer. More than 61% of the sample had a 20-20-15 nutrient composition, and 10% were complex fertilizers, which contain all nutrients in a single granule, as opposed to mixed fertilizers, which are made by physically mixing granules of straight fertilizers for each nutrient.[11]

Table 1. Basic statistics of sample fertilizers

	Obs.	Share	
Fertilizer type			
16-16-08	141	0.142	
20-20-15	141	0.610	
25-25-05	141	0.121	
Others	141	0.128	
Province			
An Giang	141	0.220	
Hậu Giang	141	0.163	
Kiên Giang	141	0.184	
Sóc Trăng	141	0.191	
Vĩnh Long	141	0.241	
	Obs.	Mean	S.D.
Price (1000VND/kg)	131	11.986	1.305
Complex fertilizer	134	0.097	dummy

Note: Observations for price and complex fertilizer are smaller due to missing price information and sample image (photo) data.

[11] It is easy to distinguish between complex fertilizers and mixed fertilizers by visual inspection because mixed fertilizers contain separate granules with different colors for different nutrients. We identified the fertilizer as "complex" if a fertilizer sample consisted of single granules.

4. Results

4.1. Quality deviation

As an indicator of fertilizer quality, we use the *deviation rate* (%), $DevRate_{ij}$, which measures the deviation of the actual nutrient content from the labeled nutrient content level:

$$DevRate_{ij} = \frac{v_{ij}^{actual} - v_{ij}^{label}}{v_{ij}^{label}} \times 100$$

where v_{ij}^{label} indicates the labeled level of the nutrient content $j \in \{N, P, K\}$ or the sum of these three nutrients in sample i, and v_{ij}^{actual} is the actual level revealed by our laboratory tests. $DevRate_{ij} < 0$ indicates that the actual j content is below the labeled content level. We also construct a *substandard* dummy variable, $SubStandard_{ij} \equiv I(DevRate_{ij} < -10)$, indicating a deviation rate below -10%, which is the legally acceptable lower limit.

Table 2 reports the deviation rates and the proportion of the sample that is substandard. The mean deviation rates for the whole sample are 3.20% (95% confidence interval (CI): 0.675-5.718) for nitrogen, −7.75% (95% CI: −10.865–−4.640) for phosphate, and −1.38% (95% CI: −6.565–3.806) for potassium (Panel A, column 1). While nitrogen is enriched, phosphate is more diluted than the labeled level. The 95% confidence interval for phosphate exceeds the legal limit of −10%. The mean deviation rate for the sum of these three nutrients is −2.5% (95% CI: −4.228-−0.675) (Panel A, column 1). Looking at the proportion of substandard samples, defined as those with a deviation rate below −10%, half (49%) of our samples have at least one substandard nutrient (Panel B, column 1). Phosphate is most likely to be deficient, with 33% of sample fertilizers being substandard, followed by potassium (21%) and nitrogen (14%). If we add up the contents of the three components (sum of N, P, and K) to calculate the *aggregate* deviation rate, 21% of the samples are substandard. In Panel C, column 1 shows that 9.2% have at least one nutrient below −50% of the level indicated on the label. Deviation rates and proportions of substandard samples vary by fertilizer type (columns 2−5), with no consistent pattern.

Table 2. Deviation rates and proportions of the substandard samples

	(1)	(2)	(3)	(4)	(5)
		By fertilizer types			
	All samples	16-16-08	20-20-15	25-25-05	Others
Observations	141	20	86	17	18
A. Mean deviation rate (%) (std. dev. In parenthesis)					
Nitrogen (N)	3.20	4.34	4.82	0.14	-2.95
	(15.1)	(15.6)	(16.0)	(11.8)	(11.9)
Phosphate (P)	-7.75	-4.97	-8.36	-12.4	-3.54
	(18.7)	(10.5)	(20.3)	(16.7)	(19.3)
Potassium (K)	-1.38	5.45	-7.02	7.55	9.55
	(31.1)	(32.1)	(29.6)	(43.5)	(15.7)
Total (N+P+K)	-2.45	0.84	-3.20	-4.89	-0.22
	(10.7)	(9.31)	(11.7)	(9.92)	(6.48)
B. Proportion of substandard samples (deviation rate < -10%)					
Any of N, P, K	0.489	0.450	0.512	0.647	0.278
Nitrogen (N)	0.135	0.150	0.128	0.176	0.111
Phosphate (P)	0.333	0.250	0.349	0.588	0.111
Potassium (K)	0.206	0.200	0.256	0.118	0.056
Total (N+P+K)	0.206	0.100	0.244	0.235	0.111
C. Proportion of substandard samples (deviation rate < -50%)					
Any of N, P, K	0.092	0.050	0.105	0.118	0.056
Nitrogen (N)	0.000	0.000	0.000	0.000	0.000
Phosphate (P)	0.028	0.000	0.035	0.000	0.056
Potassium (K)	0.078	0.050	0.093	0.118	0.000
Total (N+P+K)	0.000	0.000	0.000	0.000	0.000

Note: This table reports the mean (Panel A), the proportion of substandard samples with a deviation rate below −10% (Panel B), and the proportion of substandard samples with a deviation rate below −50% (Panel C). The standard deviation is reported in the parentheses for Panel A. Column 1 reports the statistics for the full sample. Columns 2−5 report the statistics by fertilizer type.

Figure 2(a) presents the histograms of the nutrient deviation rates. **Figure 2(b)** depicts normal probability-probability (P-P) plots to diagnose the distributions of the deviation rates against normal distributions. Phosphate and potassium are more skewed to the left than the normal distribution. **Table 3** shows the skewness, kurtosis, and skewness/kurtosis tests for normality. Negative skewness and normality tests indicate that the left tail of the distribution is indeed longer for these two nutrients. However, it is important to note that almost 30% of the sample is concentrated at a deviation rate of about 0%. In other words, about one-third of the sample is accurately produced at the exact content level as labeled.

The finding that 21% of the samples are substandard for the sum of three nutrients is alarming. Of these 29 substandard samples, 8 samples (28%, or 6% of all 141 samples) were deficient in all three nutrients (**Table 4**).[12] Since all nutrients are diluted together, these samples could be a product of simple dilution by the addition of foreign matter such as sand. Another possibility is intentional or unintentional mislabeling, such as 16-16-8 fertilizers being labeled as 20-20-15. However, for the vast majority (72%) of the substandard samples based on the aggregated deviation rate, we see that some nutrients are over-concentrated, while others are diluted. This pattern is inconsistent with simple dilution or mislabeling.

In summary, our results have three implications. First, on average, farmers can rely on the label. Second, we cannot completely rule out the possibility of deliberate dilution or mislabeling. Third, farmers have a half chance of buying a product with at least one nutrient content below the legal limit. Overall, the biggest problem is the variability in nutrient composition: some nutrients are in excess, while others are deficient.

[12] These are samples with id 4, 6, 7, 11, 15, 23, 24, and 29.

Figure 2. Distribution of deviation rates by nutrient

Note: Panel (a) depicts histograms of the deviation rates. The dashed vertical lines at −10% indicate the legally permissible level of the deviation rate. Panel (b) shows the normal P-P plots. The y-axis is the cumulative distribution of the samples. All points are plotted along the diagonal line if the data are normally distributed.

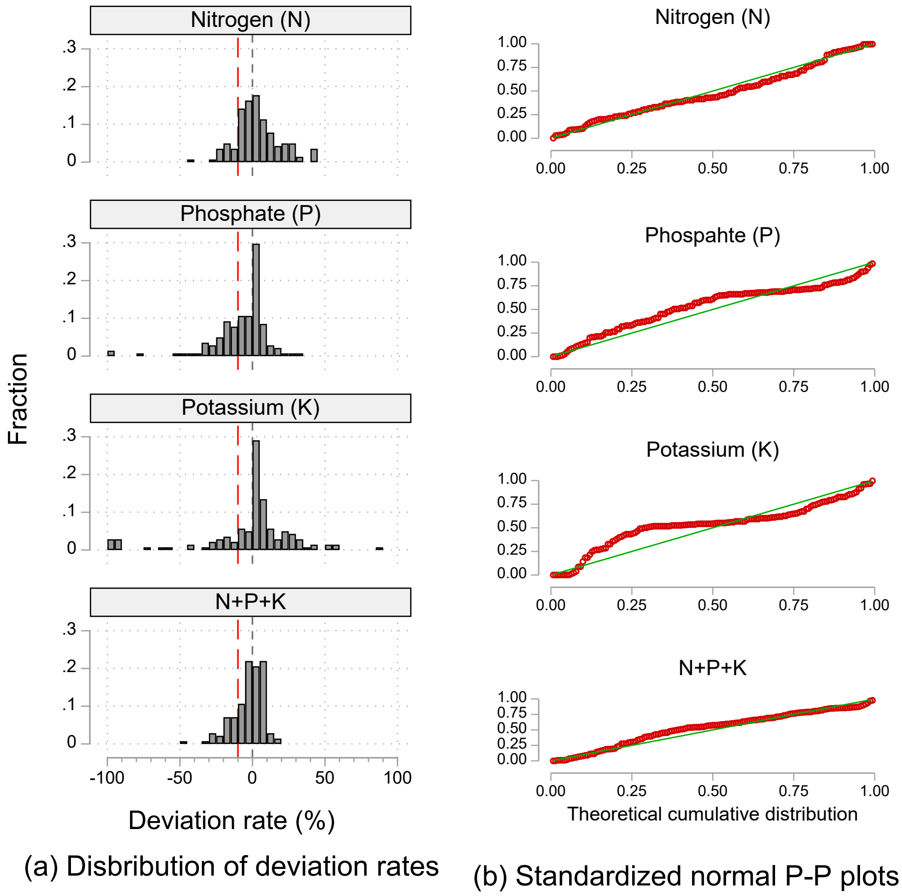

Table 3. Diagnosis of the distributions of deviation rates

Note: This table shows the skewness and kurtosis tests for normality.

	(1)	(2)	(3)	(3)
	Deviation rate (%)			
	Nitrogen (N)	Phosphate (P)	Potassium (K)	N+P+K
Obs.	141	141	141	141
Mean	3.197	-7.753	-1.379	-2.451
S.D.	15.147	18.695	31.143	10.670
Skewness	0.480	-2.093	-1.327	-1.124
Kurtosis	3.653	10.443	6.117	4.924
Prob. Skewness	0.0198	0.0000	0.0000	0.0000
Prob. Kurtosis	0.1097	0.0000	0.0001	0.0020
Joint adj chi2(2)	7.35	59.47	33.38	24.92
Joint Prob>chi2	0.0253	0.0000	0.0000	0.0000

Table 4. Details of the deviation rates for substandard samples based on aggregate deviation rate

Note. The negative deviation rate is highlighted in red and the positive is highlighted in blue.

Seq.. id	Fertilizer type	Nutrient contents				Deviation rates (%)			
		Nitrogen	Phosphate	Pottasium	N+P+K	Nitrogen	Phosphate	Pottasium	N+P+K
1	20-20-15	28.5	0.0	0.3	28.8	43	-100	-98	-48
2	20-20-15	19.3	0.6	15.9	35.8	-4	-97	6	-35
3	20-20-15	29.0	9.5	1.3	39.8	45	-52	-92	-28
4	20-20-15	15.2	13.3	11.6	40.1	-24	-34	-23	-27
5	25-25-05	26.0	14.0	0.2	40.2	4	-44	-97	-27
6	20-20-15	19.3	10.2	10.6	40.1	-4	-49	-29	-27
7	20-20-15	18.1	13.5	9.8	41.4	-9	-33	-35	-25
8	20-20-15	24.7	17.5	0.9	43.1	24	-13	-94	-22
9	25-25-05	21.5	15.3	6.6	43.4	-14	-39	32	-21
10	16-16-08	16.3	11.2	4.5	32.0	2	-30	-44	-20
11	20-20-15	18.0	14.2	12.1	44.3	-10	-29	-19	-19
12	20-20-15	25.7	18.0	1.1	44.8	29	-10	-92	-18
13	20-20-15	24.7	19.9	0.5	45.1	24	-1	-97	-18
14	20-20-15	21.0	13.8	10.6	45.4	5	-31	-29	-17
15	20-20-15	18.4	14.6	12.7	45.7	-8	-27	-15	-17
16	16-16-08	12.4	12.8	8.1	33.3	-23	-20	1	-17
17	Others	20.0	4.8	23.3	48.1	-9	-76	55	-16
18	25-25-05	26.3	20.0	0.3	46.6	5	-20	-94	-15
19	20-20-15	25.1	21.1	0.4	46.6	26	6	-97	-15
20	20-20-15	23.3	13.0	11.1	47.4	16	-35	-26	-14
21	25-25-05	24.7	17.9	5.0	47.6	-1	-28	1	-13
22	Others	9.4	16.3	16.1	41.8	-41	2	1	-13
23	20-20-15	19.6	14.5	14.0	48.1	-2	-28	-7	-13
24	20-20-15	16.5	18.2	13.7	48.4	-18	-9	-9	-12
25	20-20-15	16.8	16.7	15.0	48.5	-16	-16	0	-12
26	20-20-15	15.0	18.5	15.0	48.5	-25	-8	0	-12
27	20-20-15	15.9	16.8	15.9	48.6	-21	-16	6	-12
28	20-20-15	14.9	17.2	16.6	48.7	-26	-14	11	-11
29	20-20-15	17.9	19.4	12.0	49.3	-11	-3	-20	-10

4.2. Price and quality deviation

Figure 3 depicts the relationship between the logged price and the deviation rates. Sample fertilizers with higher quality deviations tend to have higher prices. **Table 5** shows the estimation results of a simple regression of price on deviation rate. Regional dummies are not included due to the small sample size. On average, sample fertilizers with ten percentage points higher deviation rates tend to have prices that are 0.1%–0.6 % higher. Columns 5 and 6 regress the substandard dummy on the logged price with threshold deviation rates of −10% and −50%, respectively. Substandard samples at the −10% threshold tend to be 0.27% cheaper than the compliant samples. However, the estimates are not significant in any case. Thus, price signals quality to some extent, but not precisely.

Figure 3. Price and deviation rate

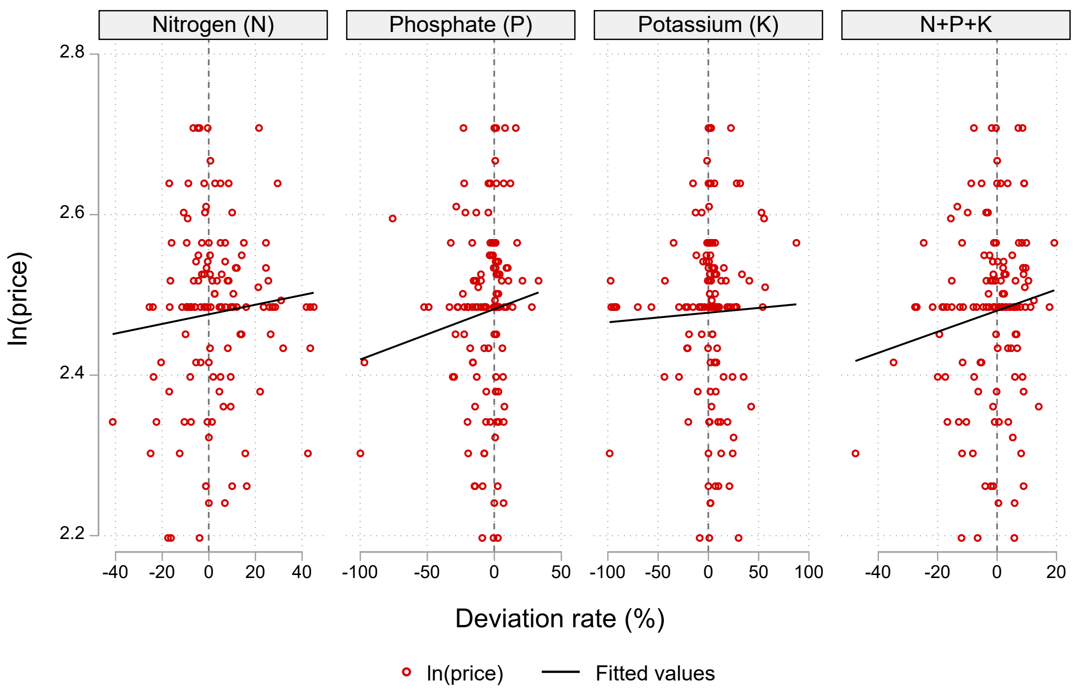

Table 5. Correlation between price and quality

	(1)	(2)	(3)	(4)	(5)	(6)
Deviation rate (%)						
Nitrogen (N)	0.000598					
	(0.000576)					
Phosphate (P)		0.000629				
		(0.000467)				
Potassium (K)			0.000119			
			(0.000232)			
Total (N+P+K)				0.00132		
				(0.000763)		
Substandard dummy						
Deviation rate <-10%					-0.0276	
					(0.0193)	
Deviation rate <-50%						-0.00293
						(0.0230)
Constant	2.476***	2.482***	2.478***	2.480***	2.491***	2.478***
	(0.0103)	(0.0105)	(0.00974)	(0.00983)	(0.0135)	(0.0104)
Observations	131	131	131	131	131	131
R-squared	0.007	0.011	0.001	0.016	0.016	0.000

Note: The outcome variable is the log (price), and its sample size is 131. The explanatory variable for columns 1–4 is the deviation rate (%) for the specified nutrient. The explanatory variable for columns 5 and 6 is a substandard dummy indicating that at least one nutrient is 10% and 50% less than the labeled amount. Robust standard errors are shown in parentheses. $* p < 0.05$, $** p < 0.01$, $*** p < 0.001$.

4.3. Compositional variations between mixed and complex fertilizers

Our results suggest that the main problem is variation in nutrient composition: some fertilizers contain too much of some nutrients and too little of others. We investigate whether there are any systematic patterns in these compositional variations. An important question is whether the quality variations are intentional or merely due to technological defects in production and quality management.

One possible cause of unintentional variation in deviation rates is inadequate stirring of straight fertilizers of different nutrients during the blending process of mixed fertilizers.[13] With inadequate stirring, nutrient composition can vary from bag to bag, even if a producer has used adequate amounts of each nutrient; for example, some bags may contain too much nitrogen while others may contain too little.

The key idea behind detecting these unintentional quality variations is that compositional variations are more likely to occur in mixed fertilizers, which simply mix straight fertilizers of different nutrients, than in complex fertilizers, which combine three nutrients in one granule.[14] Thus, if insufficient stirring is the main cause of quality diversity, we expect an apparent negative correlation of the deviation rates between nutrients contained *in* a sample fertilizer for mixed fertilizers, but not for complex fertilizers. To this end, we examine the distributions of multiple nutrients contained, in contrast to existing studies that focus only on the distribution of nitrogen (Ariga et al. 2019; Bold et al. 2017; Michelson et al. 2021).

We find two differences between mixed and complex fertilizers (**Table 6**). First, mixed fertilizers have greater variability in deviation rates than complex fertilizers. Table 6, panel (a) shows that the mean and standard deviation of the absolute deviation rates for all three nutrients are larger for mixed fertilizers. Second, the compositional variation, which we mean by the distribution of the deviation rates *among* nutrients *within* a sample, is also greater. For each sample i, we first calculate the mean of three absolute deviation rates for each nutrient. We then take the sample average of these means and standard deviations, separately for mixed and complex

[13] Similar compositional variations can occur due to segregation of nutrient granules *within a bag* of mixed fertilizer during transport or storage; heavier granules fall below lighter granules within each bag. However, we stirred the fertilizers well before sampling, so we rule out this channel.

[14] Compositional variations due to poor stirring of nutrients can also occur with complex fertilizers before three nutrients are compunded into granules.

fertilizers. The mean absolute deviation rate for mixed fertilizers is higher than for complex fertilizers (15.1% vs. 9.9%; panel (b)). These observations indicate that mixed fertilizers have greater variability in deviation rates, both for each nutrient and for the nutrient composition. This is consistent with the idea that mixed fertilizers are more susceptible to inadequate stirring, or with the view that the production of complex fertilizers requires more advanced technology and these producers have better manufacturing precision.[15]

If poor stirring is the cause of the quality deviation, we would expect to see a negative correlation of the deviation rates between nutrients within a sample (i.e., if there is an excess of one nutrient, then we should observe a deficiency of others), but such a correlation should be observed for mixed fertilizers but not for complex fertilizers (because three nutrients are compounded in one granule). **Figure 4** shows the deviation rates between the three sets of binary combinations of nutrients, and nitrogen vs. phosphate and potassium, by complex and mixed fertilizer. It is clear from the figure that the deviation rates are more limited for complex fertilizers than for mixed fertilizers, indicating the superior quality of complex fertilizers. **Table 7** reports the estimation results of the regression of the deviation rates of nitrogen (N) or potassium (K) on the deviation rates of the remaining nutrients. The relationship between the deviation rates is complex. We observe a significant negative correlation between the deviation rates of nitrogen and potassium, or nitrogen and the remaining two nutrients, potassium and phosphate (P) for mixed fertilizers. The correlations between nutrients for complex fertilizers are null except for the substitution between phosphate and potassium. Overall, while inconclusive, our results are arguably consistent with the pattern that may be caused by unintentional compositional variations due to poor stirring particularly for mixed fertilizers.

[15] Table 6, panels (c) to (e), also suggests that mixed fertilizers may be of lower quality than complex fertilizers, as indicated by more negative deviation rates for phosphate and potassium. The proportion of substandard samples is also lower for complex fertilizers than for mixed fertilizers (except for nitrogen).

Table 6. Comparison between mixed vs. complex fertilizers on quality

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	All samples (n=141)		Complex fertilizers (n=13)		Mixed fertilizers (n=121)		Complex vs. mixed fertilizers		
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Difference	S.E.	*p*-value
(a) Absolute deviation rate (%)									
Nitrogen (N)	11.285	10.556	9.150	11.416	11.751	10.527	2.601	(3.212)	0.419
Phosphate (P)	12.429	15.951	7.365	6.569	13.209	16.814	5.843	(2.337)	0.014 *
Potassium (K)	18.987	24.672	13.218	11.513	20.445	26.034	7.227	(3.898)	0.066
Total (N+P+K)	7.830	7.625	5.064	3.770	8.256	7.945	3.192	(1.245)	0.011 *
(b) Compositional variation									
Mean absolute deviation rate of N, P, and K within sample	14.628	12.960	9.911	6.192	15.135	13.403	5.224	(2.106)	0.010 *
(c) Deviation rate (%)									
Nitrogen (N)	3.197	15.147	-2.837	14.571	3.751	15.358	6.588	(4.155)	0.115
Phosphate (P)	-7.753	18.695	-0.788	10.062	-9.358	19.244	-8.57	(3.222)	0.009 **
Potassium (K)	-1.379	31.143	13.218	11.513	-2.9	33.027	-16.12	(4.316)	0.000 ***
Total (N+P+K)	-2.451	10.67	1.504	6.289	-3.251	11.008	-4.755	(1.964)	0.017 *
(d) Sub-standard (Deviation rate < -10%)									
At least one of NPK	0.489	0.502	0.308	0.480	0.529	0.501	0.221	(0.137)	0.108
Nitrogen (N)	0.135	0.343	0.154	0.376	0.14	0.349	-0.0134	(0.106)	0.900
Phosphate (P)	0.333	0.473	0.231	0.439	0.364	0.483	0.133	(0.126)	0.292
Potassium (K)	0.206	0.406	0.000	0.000	0.231	0.423	0.231	(0.0386)	0.000 ***
Total (N+P+K)	0.206	0.406	0.077	0.277	0.231	0.423	0.154	(0.0839)	0.068
(e) Sub-standard (Deviation rate < -50%)									
At least one of NPK	0.092	0.290	0.000	0.000	0.107	0.311	0.107	(0.0284)	0.000 ***
Nitrogen (N)	0.000	0.000	0.000	0.000	0.000	0.000	0		
Phosphate (P)	0.028	0.167	0.000	0.000	0.033	0.18	0.0331	(0.0164)	0.046 *
Potassium (K)	0.078	0.269	0.000	0.000	0.091	0.289	0.0909	(0.0263)	0.001 ***
Total (N+P+K)	0.000	0.000	0.000	0.000	0.000	0.000	0		

Note: Columns 1-6 report the mean and standard deviation. Columns 7-9 report the regression coefficient and robust standard errors (in parentheses) regressing the outcome variables on the mixed fertilizer dummy. $* p < 0.05$, $** p < 0.01$, $*** p < 0.001$.

Figure 4. Correlation of deviation rates

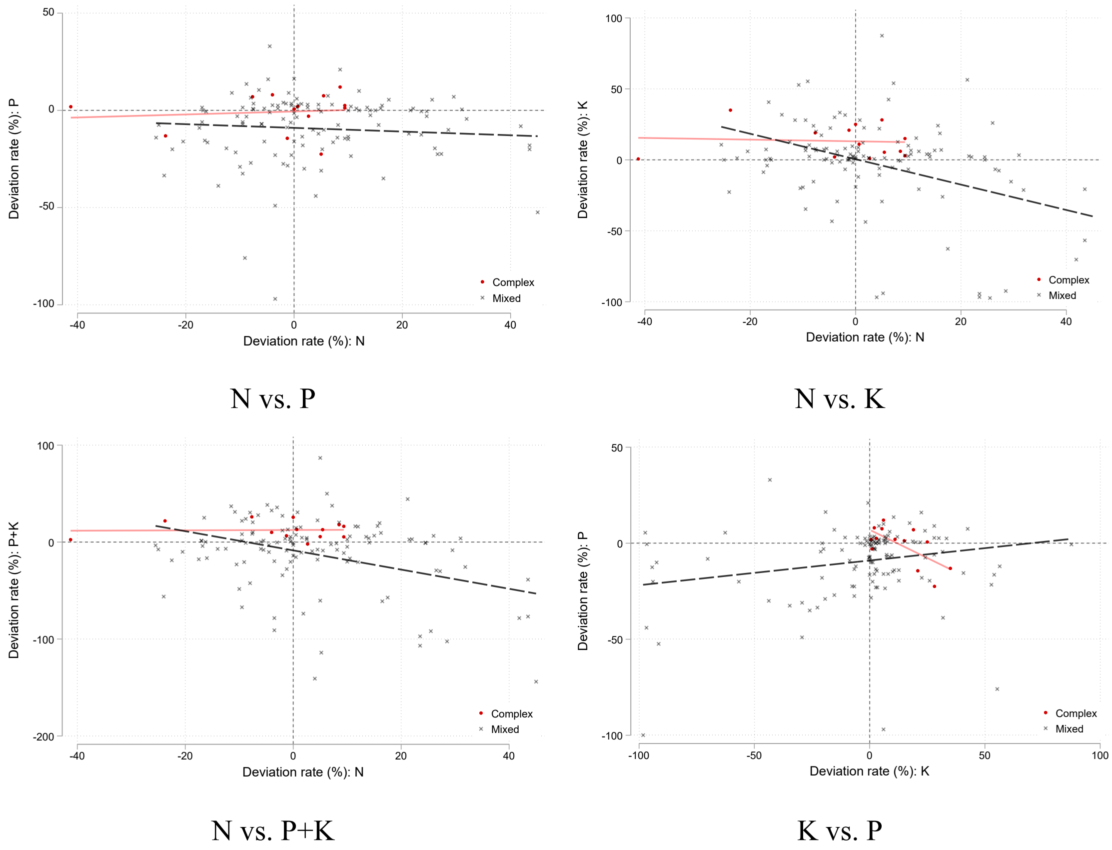

Table 7. Correlation of deviation rates between nutrients

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Deviation rate (%): N (nitrogen)						Deviation rate (%): K (pottasium)		
	All samples	Complex	Mixed	All samples	Complex	Mixed	All samples	Complex	Mixed
Deviation rate (%), N (nitrogen)							-0.814***	0.00000778	-0.864***
							(0.182)	(0.225)	(0.194)
Deviation rate (%), P (phosphate)	0.0248	0.162	0.0134				0.318	-0.769**	0.327
	(0.0633)	(0.466)	(0.0642)				(0.174)	(0.185)	(0.187)
Deviation rate (%), K (potassium)	-0.201***	0.0000224	-0.195***						
	(0.0411)	(0.648)	(0.0414)						
Deviation rate (%), P + K				-0.133***	0.0485	-0.134***			
				(0.0341)	(0.536)	(0.0344)			
Constant	3.112**	-2.710	3.310*	1.984	-3.440	2.107	3.688	12.61***	3.398
	(1.187)	(11.12)	(1.293)	(1.163)	(9.341)	(1.259)	(2.228)	(2.429)	(2.650)
Observations	141	13	121	141	13	121	141	13	121
R-squared	0.166	0.012	0.173	0.120	0.001	0.133	0.202	0.451	0.209

Note: The dependent variable is the deviation rate of phosphate (P) for columns 1–3 and the deviation rate of potassium (K) for columns 4–6. Robust standard errors are reported in parentheses. $*p < 0.05,\ **p < 0.01,\ ***p < 0.001.$

5. Discussion

5.1. Summary of the findings

Our testing of 141 sample fertilizers shows that, on average, unbranded fertilizers in the Mekong Delta region of Vietnam contain the nutrient content as labeled, but with wide variation. Prices are negatively correlated with deviation rates, but are too noisy to serve as a signal of quality. The results are consistent with the reports that farmers do not express strong concerns about fertilizer quality, nor do they adjust fertilizer use accordingly (Kojin et al. 2023). This is in contrast to SSA, where farmers tend to (mis)perceive fertilizer quality as poor and apply inadequate amounts (Michelson et al. 2021).

We sought to investigate the sources of the compositional variation. We find that mixed fertilizers have greater variability for the deviation rate of each nutrient as well as copositional variations between nutrients within a sample. Interestingly, nitrogen tends to mask the phosphate deficiency.

5.2. Generalizability and sampling issue

Our results may overstate the quality variation and low quality fertilizers in Vietnam because our purposive sampling focused on the high-risk market segment of low quality fertilizers. We sampled only from certified fertilizer retailers. The extent of uncertified retailers is unknown, but by definition, these stores are not allowed to sell the products. Since retailers are regularly inspected, it is likely that unlicensed stores are the exception. The major brands, which we intentionally excluded from our sample, are likely to be of more stable quality with little deviation from the label because they are regularly inspected to renew their production and distribution licenses and voluntarily provide quality guarantees (Kojin et al. 2023). In addition to the major brands, new brands are also mushrooming all over the market, and are sold at lower prices to attract customers.

Our analysis shows that the quality of these cheap, unbranded products is decent on average, but with non-negligible variation, possibly indicating the inability of producers to control quality. An important implication is that, despite the large heterogeneity across samples, average quality is driven by regulation rather than reputation, because our samples are unbranded. This underscores the importance of public regulation in the governance of the markets for experience goods (see Section 2.1).

The weak correlation between price and quality may be due to sample selection bias, as we intentionally selected the cheapest fertilizer product in each retailer. However, since we find that the mean deviation rates are close to zero, even for these purposefully selected samples, it is likely that price-quality correlations will not be strong when we include branded fertilizer products.

A limitation of our sampling strategy is that we did not uncover direct sales by small producers,[16] including newly established ones, who are likely to have received fewer inspections and have less production knowledge and technology. This will understate the overall picture of the fertilizer quality problem, but we believe that this channel is not large enough to invalidate our conclusion. However, further studies are needed to clarify the situation in this channel.

5.3. Comparison with other studies

The situation in Vietnam contrasts with SSA, where farmers tend to (mis)perceive fertilizer quality as poor and apply inadequate amounts. We find that 49% of the samples in Vietnam are out of compliance for any of nitrogen, phosphate, or potassium, containing less than 90% of the labeled nutrient level, and the non-compliance rate for nitrogen is 14%. In contrast, Michelson et al. (2021) found that 23% (146 out of 633) of samples from agro-dealers in Tanzania were out of compliance (containing less nutrients than the legal standard) for nitrogen. What surprises us is the low deviation rate in Tanzania, which has not established adequate regulatory systems (Michelson et al. 2021). However, as we suggest in this study, we may be able to learn more about the low-quality fertilizer problem and draw policy implications by looking at compliance rates for the three major nutrients rather than focusing solely on nitrogen.

Although more research is needed to make a more comprehensive international comparison of the extent of the problem, we believe that the situation in Vietnam is settling down. As we discussed in section 2.2, there are public and market initiatives underway to manage fertilizer quality. It is possible that these initiatives will be effective in mitigating the problem.

5.4. Over-concentration of nitrogen

The over-concentration of nitrogen (mean deviation rate of +3%) needs some discussion. It is not clear why this occurs. Possibilities include mislabeling, inadequate technology

[16] Large producers are more likely to rely on their distribution channels (Figure 1) and avoid the high transaction costs of selling directly to farmers.

(manufacturing defects), and deliberate addition of nutrients. There are potential incentives for manufacturers to over-concentrate nitrogen to stimulate crop growth and to impress farmers that the product is of better quality than others (suggested by a fertilizer expert). While the magnitude of over-concentration is small, overuse of nitrogen in general can cause soil acidification, water pollution (eutrophication), and air pollution through the emission of greenhouse gases such as nitrous oxide (Cassou 2018).

5.5. Causes of compositional variations

Given our small sample size, we were unable to draw firm conclusions on the causes of compositional variation. We found a consistent pattern of variation in deviation rates that would be predicted by inadvertent technical problems due to poor stirring during production. Taken together with the evidence that mixed fertilizers had a higher deviation rate than complex fertilizers, and that mixed fertilizers do not require high technology to produce, selection for low-skilled manufacturers to produce mixed fertilizers may be a leading explanation for the cause of compositional variation.

Another possibility is intentional deviation by profit-maximizing and dishonest fertilizer manufacturers, who reduce costly nutrients and increase less costly nutrients instead. The observed compositional variations show that nitrogen is being enriched while phosphate is being diluted. The most recent USDA survey of fertilizer prices shows that phosphate is more expensive than nitrogen and potassium (USDA 2019).[17] In addition, potassium is particularly expensive or difficult to source for fertilizer producers in Vietnam. According to our interview with a large fertilizer producer in August 2019, they procured all materials from their group companies, except for potassium, which they imported (see also Bui (2019)). Thus, the observed pattern is consistent with profitable deviation, where producers use cheaper nitrogen instead of potassium.

6. Conclusion

To investigate fertilizer quality in Vietnam, we tested the nutrient content of 141 fertilizer samples in the Mekong Delta region. We deliberately sampled the unbranded products to focus on the market segment where the low quality fertilizers are most likely to be found. We found

[17] The price of urea containing 44-46% of nitrogen was 571 dollars per ton as of 2014, the price of super-phosphate containing 44-46% of phosphate was 621 dollars per ton, and the price of potassium chloride containing 60% of potassium was 601 dollars per ton (USDA 2019).

that, on average, the fertilizers contain the nutrient content as labeled. However, there are large variations between samples. Half of the samples did not meet the legal requirements for at least one of the three main nutrients and 21% of the samples are identified as substandard based on the aggregate deviation rates. In 6% of the samples, all three nutrients were below the labeled levels. In addition, some fertilizers have too much of some nutrients and too little of others.

The results suggest that the quality of unbranded fertilizers in Vietnam is reliable in the sense that labels can be trusted, but we cannot rule out the possibility of simple adulteration by adding contaminants or mislabeling. The presence of large variations in quality suggests that there is room for improvement in stabilizing quality. In addition, the finding that nitrogen is over-concentrated on average, may warrant policy attention, as farmers may inadvertently over-apply nitrogen and harm the environment.

Due to our targeted sampling focus on unbranded products, further investigation of the segments that were excluded from our study is needed to fully uncover fertilizer quality in Vietnam. Sampling from large producers, which account for most of the market share and which we assumed to have a near-zero deviation rate with low variability, and direct sales from local small and medium producers, which are concerned about low quality, are the remaining segments.

Identifying the causes of quality variation is important to guide policy implications. We have also focused on only a few specific potential causes of quality variation. Further understanding of the production process, cost structures, and incentives for producers to reduce or over-concentrate individual nutrients, as well as technical difficulties and problems, will narrow down a more rigorous and specific hypothesis.

Finally, a fundamental question is when and how regulation or reputation can govern the market for the experience goods. Our results suggest that regulation is important in our context because our samples are unbranded and have no reputation. Future studies could also examine policies that induce and support market initiatives under limited administrative capacity, typically in developing countries. Frequent inspections, their announcement, and third-party quality testing services (Saenger et al., 2014) are potential candidates for such policies.

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