Governance of fertilizer quality in Vietnam: government and market initiatives

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March, 2022

Abstract

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Keywords: low-quality fertilizer, experience goods, Vietnam

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1. Introduction

Fertilizers are indispensable for improving agricultural productivity and food security (Evenson and Gollin, 2003; Foster and Rosenzweig, 2010; Njeru, Mano, and Otsuka, 2015). However, many developing countries suffer from the prevalence or farmers' (mis)perceptions about low-quality fertilizers in the market (Ariga, Mabaya, Waithaka, and Wanzala-Mlobela 2019; Bold, Kaizzi, Svensson, and Yanagizawa-Drott 2017; Michelson, Fairbairn, Ellison, Maertens, and Manyong 2021). These concerns about fertilizer quality hinder the adoption and use of fertilizers, leading to low farmer profitability and stagnation of agricultural productivity.[1] Controlling fertilizer quality in the market is vital for the wellbeing of the agrarian economy, the development of agriculture, and ensuring a stable supply of food. Knowledge of practical policies and initiatives to mitigate this problem is required.

We study the problem of low-quality fertilizers in one of the largest rice-producing and exporting countries, Vietnam. We aim to examine the fertilizer quality in the market and to discover and describe government and market initiatives[2] taken against this problem. To investigate fertilizer quality in the market, we purchased 141 samples of NPK (three-component fertilizer providing nitrogen, phosphate, and potassium) or DAP (diammonium phosphate) fertilizers sold by randomly selected fertilizer retailers in the Mekong Delta region. We implemented a laboratory test to evaluate the nutrient content and to compare them with the labeled levels. We also conducted in-depth interviews and discussions with soil/fertilizer scientists and stakeholders such as government officials, fertilizer producers, retailers, and farmers to gain information and insights on the government and market initiatives, their implementation and effectiveness, and perceptions related to fertilizer quality.

We find that our sample fertilizer contains the nutrient content as labeled on average. The average deviation rates between the actual and the labeled content are small; nitrogen slightly exceeds the labeled level (+3.2%), whereas phosphate and potassium tend to be lacking (-7.8% and -1.4%, respectively). Consistent with this finding, none of the interviewed farmers mentioned that fertilizer quality is a serious issue, nor did they claim that they reduce the fertilizer application because of quality concerns.[3] However, we find a large diversity in fertilizer quality, and half of our samples have at least one nutrient below the legal standards. Price is positively correlated with deviation rates but too noisy to infer the actual quality precisely.

We document government and market initiatives to control fertilizer quality in markets. We identify three major initiatives. First, the government has tightened direct control through a comprehensive regulatory framework, which consists of (i) licensing over production, distribution, retail, and inspection, (ii) mandatory quality labeling, and (iii) random inspections. The

[1] Other major obstacles to adoption of fertilizers include lack of knowledge and information, credit constraints, costs, uncertain and/or lower than expected returns, and behavioral constraints. See Foster and Rosenzweig (2010), Magruder (2018), and Macours (2019) for a recent review on technology adoption including fertilizers in agriculture, and Jayne, Mason, Burke, and Ariga (2018) and Holden (2019) for critical reviews on fertilizer subsidies to foster adoption. Carter, Laajaj, and Yang (2021) report positive effects of input subsidy programs in Mozambique on technology adoption and persistence using randomized controlled trial.

[2] We opt not to refer to "public" and "private" initiatives, as many (large-scale) enterprises in Vietnam are state-owned.

[3] It is difficult for farmers to recognize the low-quality problem when the deviation is not large (Bold et al. 2017).

regulations are constantly updated during the past decade. But there remains room for improvement in reducing the complicated structure of regulations, better coordination between different government entities, strengthening inspection, and compliance on the government side. Our interviews with retailers confirm that government control has indeed been implemented and complied with. Second, large fertilizer producers have already established well-known brands. Some producers offer a warranty to wholesalers and retailers for losses related to quality issues. Other producers are introducing a dealer certification to manage and control the distribution chain. Third, farmers and retailers are building a unique centralized social learning mechanism. Farmers are trying their best to learn fertilizer quality by carefully observing crop growth. Farmers' quality assessments are aggregated to retailers through feedback (complaining of poor quality). Equipped with multiple quality signals, some retailers switch their product assortments to remove products that are likely to be of low quality.

These observations suggest that the Vietnamese situations are different from what has been reported for Africa where farmers hold (mis)perceptions about low-quality fertilizers (Ariga et al. 2019; Bold et al. 2017; Michelson et al. 2021): the average fertilizer quality is fair; farmers report no concern over fertilizer quality; standard regulatory frameworks are installed and implemented; market initiatives and social learning mechanisms seem to be working to eliminate low-quality products. However, an effort is still needed to reduce the quality variability. The case of Vietnam may suggest that the combination of government regulations and private initiatives of branding and reputation-building can mitigate the fertilizer quality problem. We emphasize that regulations and branding are complementary: producers' effort of providing high-quality products is not credible without quality standards, labeling obligations, and third-party inspections. For the producers to pursue branding, a set of regulations is necessary.

Vietnam is an interesting case to study because it is one step ahead of Africa on the governance of fertilizer quality. Rice yield began to increase in the 1980s, accompanied by the increase in fertilizer inputs. Currently, Vietnam is one of the leading rice-producing and exporting countries in the world.[4] It also ranks high in intensive fertilizer use. Like other countries, Vietnam has faced low-quality fertilizers during the transition from traditional to modern farming systems that involve intensive use of chemical fertilizers.[5] The government has introduced and updated regulations to deal with this problem. Vietnam also has a developed fertilizer market with the emergence of large-scale (state-owned) producers who establish brands and a high reputation for quality.[6] The Vietnamese case provides insight into the role of government regulations as well as nature and methods by which business entities can mitigate the problem.

This study is related to the literature on low-quality agricultural inputs, which has almost wholly focused on Africa. Several studies have investigated the prevalence or perceptions of fake or low-quality agricultural inputs, including fertilizers (Bold et al. 2017; Hoel, Manyong,

[4] Vietnam is the fifth-largest rice producer in the world producing 44 million tons of rice in paddy and the third-largest exporter, exporting 5.8 million tons in 2018 (FAOSTAT).

[5] For example, Japan has also experienced the same problem where low-quality fertilizer prevailed in the market after the introduction of chemical fertilizers in the early 20th century (Matsumoto and Sakane 2017; Takahashi 2010). Even today, cases exist of fertilizers being contaminated with substances such as sludge or chemicals that are not permitted for use in fertilizers. They are exposed as violations and false labeling (MAFF 2018).

[6] Ariga, Mabaya, Waithaka, and Wanzala-Mlobela (2019) propose development stages of fertilizer markets. Vietnam can be placed in the category of early to late developmental stage as per their classification.

Michelson and Norton 2021; Michelson et al. 2021) and herbicides (Ashour, Gilligan, Hoel and Karachiwalla 2018). The critical question has been whether consumers can correctly identify quality from experience or social learning and why equilibrium with different qualities or misperceptions persists.

We contribute to the literature by providing a comprehensive picture of government and market initiatives to address this issue in the context of Vietnam. Policy evaluation of specific measures such as e-verification (Gillgan, Karachiwalla, and Thai, 2019) is helpful for understanding "what works", once a policy that is considered effective is specified. Understanding of political and economic environment surrounding the fertilizer quality is essential to specify the candidate interventions. We highlight the importance of public regulations by discussing how government and market initiatives interact and complement each other.

We also add to the literature by providing an estimate of the prevalence of low-quality fertilizers in Asia. Most other studies have uncovered the situation in Africa with mixed results, causing a debate on whether the reported test results are prone to measurement error (Hoel et al. 2021)[7]. Our results provide a reference of comparison in the context with different stages of government regulation and development of fertilizer markets.

Finally, we touch on the unstudied implications of low-quality fertilizers: *over*-fertilization. Despite the reported prevalence of low-quality fertilizers in the markets, farmers in Vietnam apply excess fertilizers. Low or unreliable quality may be a driver of over-fertilization because farmers over-apply fertilizers to cover up the missing nutrients (Nguyen 2017). This possibility has not been explored in the literature, and we discuss its validity. Our in-depth interviews suggest that fertilizer quality is unlikely to be the cause of over-fertilization. Instead, the most likely cause seems to be crop intensification due to the expansion of triple cropping, substitution for shortage of labor, and poor knowledge on appropriate fertilizer usage.

The paper proceeds as follows. Section 2 describes the conceptual background of the problem of fertilizer quality and the contextual background of Vietnam. Section 3 describes the data and the results of fertilizer quality in the market. Section 4 describes government and market initiatives taken against the problem. Section 5 summarizes the findings and discusses its implication. We conclude in Section 6.

2. Conceptual framework and background

2.1. Fertilizers as "noisy" experience goods

We consider fertilizers in Vietnam *low quality* when the nutrient content is lower than the label on the package. Formally, it is *sub-standard* if the contents are lower by 10% (see Section 4.1). The production of low-quality fertilizers may or may not be intentional.[8] Intentional low-quality production may occur as producers' moral hazard to reduce production costs by using inappropriate ingredients or mixing contaminants or supplements. Another possibility is the inability to produce fertilizers with target nutrient content. This unintentional inadequacy in

[7] A post on the World Bank Development Impact Blog (2021) titled "Devil in the details: measuring agricultural input quality" indicates that a first round of the testing in Africa suggested shortfalls in nutrient content but second round test (double-testing) in US-based laboratory showed no evidence of nutrient deficiency.

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

fertilizer quality could be driven by inappropriate production processes or poor production technology, quality control, lack of expertise in chemical knowledge, or problems during storage and transportation.

In principle, low-quality goods (i.e., "lemons") can be excluded from the market by reputation mechanisms; consumers continue purchasing a high-quality product but stop once they find it low quality, and producers or suppliers ensure to supply high-quality products because the loss of loyal consumers (i.e., loss of reputation) is costly (MacLeod, 2007). This mechanism fails for fertilizers because consumers cannot make precise inferences about their quality. Fertilizers are "noisy" experience goods in the sense that consumers can only observe at most noisy signals on quality after use. Fertilizer quality is reflected and (partly) revealed by the growth of crops and ultimate output but these quality signals are noisy. Growth and output are also affected by other factors, such as soil or weather conditions and the quality of other inputs and agricultural practices. When consumers continue purchasing the product regardless of product quality, the reputation mechanism fails, and producers have little incentive to maintain their reputation by supplying high-quality goods (Bold et al. 2017). This failure of reputation mechanism is a common problem for other noisy experience goods such as seeds, pesticides, herbicides, or anti-malaria drugs (Ashour et al. 2018; Björkman-Nyqvist, Martina, Svensson, and Yanagizawa-Drott 2022).

In theory, farmers respond to the diffusion of low-quality fertilizers by under-utilization because of low expected marginal return. However, farmers may over-apply fertilizers to compensate for the low effectiveness (due to missing nutrients). Indeed, Vietnamese farmers apply fertilizers beyond the amount applied in other countries or the optimal amount recommended by the government. Nguyen (2017: 47) states that low and unreliable quality is a driver of the over-application of fertilizers in Vietnam. We discuss if this is the case in section 4.3.

2.2. Vietnamese agriculture in the *doi moi* era

Since the transition to the market economy in the mid-1980s, agricultural production in Vietnam has dramatically expanded. In particular, rice production increased faster than the policy target, as soon as *doi moi* began in 1986. Before *doi moi*, rice cultivation was stagnant to the point where it was unable to meet domestic demand. The leading causes behind this stagnation were severe natural disasters, in addition to the decline in farmers' motivation to produce under a centrally planned economy. However, Vietnam succeeded in significantly increasing its rice production within a few years after *doi moi* began (Figure 1(a)) and has maintained its position as the second to third-largest rice exporter in the world since 1997. The factors behind the enhanced rice production in the early period of *doi moi* were the increased motivation of farmers to produce rice and technological improvements in production, such as the maintenance of irrigation and the promotion of modern varieties. While the production and export of various crops such as coffee, aquaculture products, rubber, cashew, vegetables, and fruits significantly expanded during the *doi moi* era, rice has been the key crop in Vietnam's agriculture, both domestic food security and export expansion. As of 2019, rice cultivation accounted for approximately 50% of the agricultural production area[9]. The Mekong Delta is the largest rice bowl, followed by the Red River delta.

In the *doi moi* period, Vietnamese agriculture, where rice cultivation is at the core, has been

[9] Based on the General Statistical Office website (accessed October 28, 2020).

carried out by small-scale farm households. Agricultural policy has encouraged the development of large-scale farms (*trang trại*) since 2000[10], but farmland consolidation has not progressed. As of 2016, more than 60% of farm households cultivated less than 0.5 hectares. In particular, the farming scale in the North is tiny, and the share of farm households that cultivated less than 0.5 hectares in the Red River Delta was 94%. Even in the Mekong Delta, where large-scale commercial farming has relatively developed, about 46% of farm households cultivated less than 0.5 hectares (GSO 2018).

== Figure 1 ==

Since Vietnam started industrialization in earnest in the 2000s, the rural economy has changed significantly.[11] Non-farm income opportunities have increased in urban and rural areas, and the members, especially the young members of farm households, have increasingly engaged in non-farm activities. This reallocation of young labor to the non-farm sector leads to the aging of the agricultural workforce. As the demand for industrial and commercial land has increased, agricultural land has declined. To respond to such changes, agricultural policies since 2010 have promoted structural reforms for qualitative growth in agriculture, including consolidating farmland, mechanization, the fourth industrial revolution in the agricultural sector, the expansion of cultivation of high value-added and safe products, and the promotion of environmentally sustainable agriculture.[12]

2.3. Fertilizer market and distribution channels

The production growth of agricultural products, especially rice, after the beginning of *doi moi*, has been followed by a rapid increase in fertilizer demand (Figure 1(b)). Imports fulfilled increasing fertilizer demand initially, but domestic production significantly increased with the use of nitrogen fertilizer such as NPK (nitrogen, phosphorus, potassium) and urea and phosphate fertilizer after the mid-2000s (Appendix Figure A1).

The key players responsible for increasing domestic fertilizer production consist of large-scale state-owned enterprises and large numbers of small fertilizer producers that emerged in the 1990s and the 2000s. According to newspaper reports, as of 2009, the number of fertilizer producers in the country increased to 300, and the number of fertilizer products distributed in the domestic market reached 3,000 (Công, 2009).

As of 2017, there were 706 fertilizer producers nationwide. Their total production capacity is 28.5 million tons per year, and the number of fertilizer products distributed in the market is more than 14,000, of which 12,000 products are NPK-fertilizers. The supply of DAP still relies on imports because its domestic production capacity does not meet the demand, both quantitatively and qualitatively. The domestic supply of NPK, urea, and phosphate, which accounts for about 70% of fertilizer demand in Vietnam, exceeds domestic use (Bùi 2019: 18-19; Vũ 2018). Most domestic fertilizer production is still carried out by large-scale state-owned enterprises that belong to either the Vietnam National Chemical Group (VINACHEM) or Vietnam Oil and Gas Group

[10] The Government Resolution no. 3 (03/2000/NQ-CP) on the farm economy.
[11] For description of structural transformation of rural Vietnam, see Liu, Barrett, Pham, and Violette (2020).
[12] Ayerst, Brandt, and Restuccia (2020) report high and rising misallocation of factor inputs across farms in Vietnamese agriculture, especially in the north, despite rapid and robust growth.

(PVN), as shown in Appendix Table 1. Vũ (2018) points out that the companies listed in Appendix Table A1 and four other large-scale companies[13] account for about 95% of the total fertilizer production in Vietnam.[14] However, producers other than these large-scale enterprises are small entities that produce various types of fertilizer products.

Figure 2 presents the fertilizer distribution channels in Vietnam. The main channel is shown as a thick red arrow, while the other channels are also highlighted. The main intermediary channels of the abovementioned large-scale companies are agents (*đại lý*), who have sufficient capital, and retailers (*cửa hàng*). Distributors (*nhà phân phối*) are another intermediary channel that often intervenes in the transactions between large-scale companies and agents or retailers[15]. Besides, although few, there are other channels: direct sales from large-scale companies to farmers (who often participate in contract farming or are large-scale) and distribution through cooperatives.

Small producers also distribute their products through channels, similar to large-scale producers. Small producers generally produce a wide variety of fertilizer products without quality assurance and branding. However, low-quality products are less likely to be distributed if small producers use intermediary channels because government regulations control each intermediary channel (agents, retailers, and cooperatives), as described in Section 4. Meanwhile, low-quality products may be distributed through the channel of direct sales from small producers to farmers, as this channel is not well regulated.

The distribution channel of imported fertilizers is not clear because of data limitations. However, it is probably distributed through channels similar to those of domestic products. According to newspaper reports, Chinese products account for approximately 50% of imported fertilizers (Minh 2018).

== Figure 2 ==

2.4. Fertilizer quality in the past

An increase in the number of fertilizer producers and products has resulted in difficulties in quality control. While the quality of domestically produced fertilizers has improved in general, low-quality or fake fertilizers have prevailed in the market for more than a decade. Table 1 lists newspaper reports showing the share of low-quality or fake fertilizers in the market. In the late

[13] Namely, Nam Sao Group, Baconco Group, General Materials Biochemistry Fertilizer Joint Stock Company (HIS), and Viet Nhat company (JVF).

[14] It is hard to confirm whether "95%" is an accurate number due to the data limitation. However, it seems accurate that the majority of domestic fertilizer production is carried out by large-scale enterprises. Bùi (2019:18) points out that 10 large-scale state-owned enterprises belonging to either VINACHEM or PVN account for the majority of annual fertilizer production amount in 2018. In addition, according to the interview survey conducted on August 22, 2019, the officials in An Giang province recognized that about 70% of fertilizer products distributed in the province were the products of large-scale companies.

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

2000s, 40%–50% of the fertilizer products on the market were reported to be of low quality. The share appears to have declined since the 2010s (especially in the late 2010s), but low-quality fertilizers have not been completely eradicated from the market until recent years. The violations include lack of ingredients as well as fake packaging for famous brands (BBC 2020; Minh 2019), counterfeiting with silicone (Minh 2018), and disguising the country of production (BBC 2020)[16].

Newspaper reports indicate several reasons for the presence of low-quality fertilizers: lack of knowledge and technology of small producers (Minh 2018; Nguyễn 2013), collusion between producers and retailers (Khánh 2017), import of low-quality or fake fertilizers (Bá 2018), corruption at the authorized organizations conducting the fertilizer tests required before the approval for distribution (Bá 2018; Chung 2017), the inadequate penalty for production and distribution of low-quality/fake fertilizers (Khánh 2017), and cheap taste of farmers especially in remote areas (Minh 2019).

Low-quality fertilizers (mainly NPK) may have negative economic and environmental impacts. Nguyen (2017: 47) links low and unreliable quality to over-fertilization in Vietnam. Data on agricultural use of fertilizers per crop area in 2016 from FAOSTAT indicate that Vietnam is indeed applying fertilizers intensively compared to other Asian countries; Vietnam ranks fourth in Asian countries, with a total of 258 kg per hectare, following China (395 kg), Korea (323 kg), and Bangladesh (261 kg). Farmers apply fertilizers beyond the recommended level (Nguyen 2017; Stuart et al., 2018), which leads to increased production costs and lower profits (Nguyen 2017: 41–43; Tran et al., 2018). Overfertilization also causes soil pollution, such as soil fertility loss (Pham 2006) and soil acidification (Crews and Peoples 2004; FAO 2003; IDH Vietnam 2013).

== Table 1 ==

3. Fertilizer quality in the Mekong Delta region

To determine the quality of the fertilizers in the market, we sample and test their nutrient content. We describe our survey and sampling methods and report the findings. In Appendix, we report additional analyses to investigate whether quality deviations are caused by incompetence during production or problems during transportation.

3.1. Data

We focus on the retail channel, as this is the largest among all the distributional channels.[17] The target population is licensed fertilizer retailers, who are required to be licensed by Decree 108 (see Section 4). We randomly selected two districts from each of the five major agrarian

[16] In 2015, an inspection by the National Steering Committee 389 revealed that Thuan Phong Company, a fertilizer manufacturing company in Long An Province, had been producing fake fertilizer with the trademark VITOL and disguising the country of production as "Made in US." Once the details of the violation were revealed, the public security of Long An Province assumed that the case was over and decided not to prosecute it. The Farmers Association, the Fertilizer Association, as well as several members of the National Assembly have called for strict punishment based on the law, but no action has yet been taken (BBC 2020; Hoàng 2020; Lê 2020,).

[17] We ruled out fertilizers distributed through farmers cooperatives or contract farming because these institutions normally internalize the profit of farmers and they do not have incentives to provide low-quality fertilizers.

provinces in the Mekong Delta region,[18] the largest rice-producing and fertilizer consumption area in Vietnam. We obtained a list of certified fertilizer retailers from the local governments.[19] We randomly sorted the listed retailers to specify the order of their visits.

We visited the sampled retailers and purchased 1 kg of either NPK or DAP[20] from November 2018 through April 2019. Upon purchase, some local co-authors portrayed themselves as ordinary customers and claimed that the fertilizer would be used for bonsai (which is popular in the Mekong Delta Region) or small gardening as a trial. We made sure not to mention that it would be tested in the laboratory or collected for research purposes.

Given the budget and logistic limitations, we specifically targeted the market segment where the prevalence of low-quality fertilizers is expected to be high. To this end, we excluded the major producers[21] and purchased the cheapest non-branded fertilizer product available in each shop. If a retailer did not sell the fertilizer in small amounts (1 kg) or sold only major brands, we left the store without purchasing anything and visited the next retailer on the list. We set the target number of retailers for each district proportional to the total number of retailers and repeated the process until the sample size reached the target number of retailers. We discuss the limitations of this sampling method in the conclusion. Upon purchase, we recorded the retailer's name, date and time of the visit, nutrient composition (for example, 16-16-8), name of producer or brand, and price of purchased fertilizer. The purchased fertilizer was doubly sealed in a zip-lock bag immediately after leaving the store.

The sampled fertilizers were immediately delivered to the Laboratory of Soil Chemistry, Department of Social Science, Can Tho University, Vietnam. A colorimetric method using a spectrophotometer was adopted, and the contents of nitrogen (N), phosphate (P), and potassium (K) were determined. The nutrient testing results and information from the retailer survey were matched with each other, resulting in 141 observations for our analysis.

Appendix Table A1 presents sample summary statistics. More than 61% of the samples were of nutrient composition type 20-20-15, and 10% were complex fertilizers in which all nutrients were contained in a single granule (compared to mixed fertilizers, which are produced by physically mixing granules of straight fertilizers for each nutrient).[22]

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[18] The selected provinces are An Giang, Hậu Giang, Kiên Giang, Sóc Trăng, and Vĩnh Long. We excluded Can Tho city because it is too urbanized, regulations are strictly implemented, and the marketing system seems well organized.

[19] For Soc Trang province, we were unable to access the list of licensed fertilizer retailers. We thus randomly selected ten communes (xã). Enumerators were asked to randomly visit two retailers for each commune.

[20] While it is a norm for farmers to purchase entire bags (typically 50kg) of fertilizers, it is also possible to purchase them in small portions.

[21] The excluded producers are Ninh Binh Phosphate Fertilizer Joint Stock Company, Binh Dien Fertilizer Joint Stock Company, Quang Binh Import & Export JSC, Lam Thao Phosphate and Chemical JSC, PETROVIETNAM Ca Mau Fertilizer JSC, PETROVIETNAM Fertilizer & Chemicals Corporation, Ha Bac Nitrogen Fertilizers And Chemical Company, Five Star International Group, Que Lam Group, Agricultural Products And Materials Jsc (Apromaco), Song Gianh Corporation, Thien Sinh JSC, Van Dien JSC, Ninh Binh Nitrogenous Fertilizer Ltd. Company, Vinachem JSC, Japan Vietnam Fertilizer Company, and Baconco Group.

[22] It is easy to distinguish between mixed fertilizers and complex fertilizers by visual inspection because mixed fertilizers contain granules by nutrients in different colors. We identified the fertilizer as “complex” if a fertilizer sample consisted of single granules.

3.2. Results

Deviation rates

We focus on the *deviation rate* (%) as an indicator of fertilizer quality. The deviation rate measures the deviation of the actual nutrient content to the labeled level. Let $DevRate_{ij}$ denote the deviation rate of the nutrient content $j \in \{N, P, K\}$ content in sample i:

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

where v_{ij}^{label} indicates the labeled level and v_{ij}^{test} is the actual level revealed by our laboratory testing. $DevRate_{ij} < 0$ indicates that the actual j content is lower than the label. We also construct a *sub-standard* dummy variable, $SubStandard_i \equiv I(DevRate_{ij} < -10)$, indicating a deviation rate smaller than -10%, the legally acceptable lower bound.

Table 2 reports the deviation rates and the share of sub-standard samples. The mean deviation rates for all samples are 3.2% (p-value for mean equal to zero: 0.013) for nitrogen, -7.8% ($p < 0.001$) for phosphate, and -1.4% ($p = 0.600$) for potassium. Thus, phosphate is more diluted than the label, whereas nitrogen is enriched. For phosphate, the mean deviation rate is not significantly different from -10 % ($p = 0.156$). Figure A2 and Table A2 in the Appendix depict the mean deviation rates by fertilizer types and province.

Half (49%) of our samples have at least one sub-standard nutrient (deviation rate below −10%). Thus, strictly speaking, half of the sample is illegal. Phosphate is most likely short, with 33% of the samples being sub-standard, followed by potassium (21%) and nitrogen (14%). Of our samples, 9.2% have at least one nutrient with less than half the labeled level.

== Table 2 ==

Distributional patterns of deviation rates

Figure 3 shows the distribution patterns of the deviation rates. Figure 3(a) shows the histograms of the nutrient deviation rate. We observe a discontinuity at a deviation rate of −10% for nitrogen, which may suggest intentional reduction of nutrients but within the legal standard[23]. We did not observe similar discontinuities in phosphate and potassium. However, the tails of the distributions of these two nutrients are broad.

Figure 3(b) depicts the standardized normal probability plots to diagnose the distributions of the deviation rates against a normal distribution. Phosphate and potassium have heavier tails than the normal distribution. Table 3 shows the skewness, kurtosis, and skewness/kurtosis tests for normality. Negative skewness and the results of tests for normality indicate that the left tail of the distribution is indeed longer for these two nutrients. However, we emphasize that nearly 30% of the samples are concentrated at a deviation rate of approximately 0%. In other words, approximately one-third of the samples are accurately produced with the exact content level as labeled.

[23] This discontinuity is unlikely to be caused by inspections because we do not observe similar discontinuities for phosphate and potash.

== Figure 3 ==

== Table 3 ==

Price and quality

Figure 4 depicts the relationship between the logged price and the deviation rates. Price is positively correlated with the deviation rates. Table 4 reports a simple correlation between price and quality; on average, samples with ten percentage points higher deviation rate tend to have 0.1%–0.6 % higher prices. Columns 5 and 6 regress the sub-standard dummy on the logged price with threshold deviation rates of −10% and −50%, respectively. Sub-standard samples at the −10% threshold tend to be 0.27% cheaper than the samples that satisfy the regulation. However, the estimates are not precise in any case. Thus, price does signal quality to some extent but not precisely.[24]

== Figure 4 ==

== Table 4 ==

4. Initiatives of fertilizer quality control in Vietnam

This section describes the initiatives for fertilizer quality control in Vietnam. First, we review the fertilizer management policy that has tightened since 2017. Second, we describe the responses of producers, retailers, and farmers. The information is based on in-depth interviews with government officials, fertilizer retailers/wholesalers, large-scale producers, farmers, and specialists on soil science and fertilizers in provinces in the Mekong Delta and Hanoi.

4.1. Government control

At the time of interviews (August 2019), the regulatory framework on fertilizer in Vietnam consists of three points, based on Decree 108 in 2017 (108/2017/NĐ-CP).

First, license or certification is required at all stages of fertilizer production, distribution, testing, importation, and sampling inspection. Table 5 summarizes the details. The licensing system requires the product to satisfy a certain quality standard, producers to hold a specific facility, retailers to be knowledgeable about the product and use of fertilizers, and inspectors to be trained on sampling. Organizations involved in issuing certification are also required to be accredited as conformity assessors.

Second, mandatory quality labeling requires producers to disclose quality. Decree 108 (article 34) mandates fertilizer products to label the nutrient contents following Decree 43 (43/2017/NĐ-CP), which specify general regulations on product labeling. Furthermore, the label's content should not differ from the content certified with the *approval of distribution*.

Third and finally, these regulations are implemented through sampling and inspections. Decree

[24] Note that lack of correlation between price and quality may be due to sample selection bias because we intentionally collected the cheapest fertilizer product in each retailer to raise the prior probability of detecting low-quality fertilizers. However, as we find that the mean deviation rates are close to zero, even for these purposefully selected samples, it is highly likely that price-quality correlations will not be observed if we include branded fertilizer products.

108 provides detailed procedures. Sampling must be carried out by a person with the *certificate of fertilizer sampling*. Besides, the fertilizer samples collected must be tested by a laboratory designated by the "Authoritative state management agencies (cơ quan quản lý nhà nước có thẩm quyền chỉ định)" with the specified testing method. Decree 108 also defines the lower limit of ingredient content associated with the registered content by the type of fertilizer. For example, NPK and DAP are required to contain more than 90% of the registered content of each nutrient.

Following Decree 108, the local government has been intensively involved in fertilizer management. For example, in An Giang province in the first half of 2018, several provincial departments conducted 11 inspections of fertilizers, pesticides, and seeds at 27 producers and retailers. Five fertilizer samples were taken for laboratory testing, and two failed to meet quality standards.[25] Violations are usually reported to the Department of Plant Protection (Cục Bảo về thực vật) of the Ministry of Agriculture and Rural Development (MARD) (hereafter, MARD-DPP) at the national level. Fertilizer products with violations are recalled, and their producers/retailers are punished at the provincial level where they are located.

== Table 5 ==

The government regulations have been updated several times since the early 2000s, where the Vietnamese government has been striving to control fertilizer quality. The first government decree on fertilizer management (Decree 113, 113/2003/NĐ-CP) was issued in 2003, just before domestic fertilizer production increased. However, the regulations in this first Decree were generally vague, causing problems in fertilizer production and distribution.

First, as the requirements for conducting a fertilizer production business were only loosely laid out, many small fertilizer producers without adequate production facilities mushroomed[26]. Second, *approval of new fertilizer* (công nhận phân bón mới) was widely obtained through political connections, as the standards for fertilizer testing required for approval were not clear.[27] Third, fertilizer management was divided between the Ministry of Industry and Trade (MOIT) and the Ministry of Agriculture and Rural Development (MARD). The division of responsibilities between the two bodies was not clear, and neither body had adequate information on fertilizer production, distribution, and import and export.[28]

In 2013, the government issued the new Decree 202 (202/2013/NĐD-CP), which replaced Decree 113 of 2003. The new Decree was enacted to address the rampant use of illicit and adulterated fertilizers that emerged in parallel with the rapid increase in the number of small fertilizer producers and products in the market. Decree 202 strengthened controls over Decree 113 in several respects, including the application procedures of the *license for fertilizer production* (Giấy phép sản xuất phân bón) and specifying detailed conditions for the sales of

[25] The report prepared by the Sub-Department of Plant Protection, Department of Agriculture and Rural Development (DARD) in An Giang province on June 12, 2018.
[26] Nguyễn (2013) and interview at Vietnam Academy of Agricultural Sciences, Soils and Fertilizers Research Institute in Hanoi (August 30, 2018).
[27] Interview at Vietnam Academy of Agricultural Sciences, Soils and Fertilizers Research Institute in Hanoi (August 30, 2019).
[28] Nguyễn (2013) and interview at Vietnam Academy of Agricultural Sciences, Soils and Fertilizers Research Institute in Hanoi (August 30, 2018).

fertilizers.[29]

However, problems remain. For example, in terms of fertilizer classification, a third classification of "other fertilizers", other than inorganic and organic fertilizers, was set without a clear definition. Moreover, two separate ministries managed fertilizer control, where MOIT managed inorganic fertilizers, while MARD was responsible for organic and "other" fertilizers. As a result, the number of fertilizer producers and products continued to increase even after Decree 202 was issued, and the problem of low-quality fertilizers remained, if not worsened. According to a newspaper report, there were as many as 4000 violations in 2015 (VNS, 2017).

Replacing Decree 202 in only four years, Decree 108 in 2017 (108/2017/ND-CP) contains many notable improvements. MARD has now been identified as the sole agency responsible for fertilizer management. Fertilizer categories are clarified with clear definitions for chemical, organic, and biological fertilizers. Most importantly, detailed regulations are set for each stage of fertilizer testing, production, distribution, and quality management.

4.2. Producers and retailers

Inspection and compliance. Our interviews with retailers suggest that regulation and control by Decree 108 are generally implemented. Most of the interviewed producers and retailers are aware of the decree. All retailers covered by our interview survey held a specified *retailer certificate* and were inspected by government officials within 12 months before the interview. The inspection involved checking whether the retailer and the salesperson held specified licenses or certificates (i.e., *retailer certificate* and *fertilizer specialist certificate*) and whether the fertilizers sold came with distribution approval.

Branding and establishing reputations. Retailers and producers are trying to improve their reputation and product quality in the following ways. First, in selecting products for sale, retailers primarily consider brands[30] because farmers are aware of major brands, and brands seem to be a critical factor in product choice, as discussed below.

Second, to strengthen branding, some large-scale producers introduced a certification to the agents in the distribution system. For example, Binh Dien Fertilizer Joint Stock Company, one of the major fertilizer producers in Vietnam with their representative brand "*Đầu Trâu*", only grants Dau Trau dealer certification (Professional Dau Trau fertilizer agent / *Đại lý phân bón Đầu Trâu chuyên nghiệp*) to agents who have received a certain level of training on fertilizer use and have passed the examination.[31] The producer expects that this system helps farmers identify trustful agents and retailers, and the producer can trust that the agent is worthwhile to sell its products.

Third, to verify quality, retailers require producers to submit the *approval of distribution* for each product in every season, as designated in Decree 108. Sometimes, retailers ask producers to send a sample of the product before proceeding to a sales contract. Retailers check the color of

[29] The Decree 202 required the following conditions for fertilizer retailers: to get business registration; to have stores and warehouses suitable for ensuring fertilizer quality; to keep legal documents that verify the producer, importer, or distributor of each fertilizer product; and to meet conditions on fire prevention, environmental protection, and labor safety.

[30] Currently, there is no exclusive agency/distributor system in Vietnam, so a retailer can deal with any fertilizer products from any producers in principle.

[31] Interview at Long An factory of Binh Dien Fertilizer Joint Stock Company (Long An factory) on August 26, 2019 and website of the company (https://binhdien.com/gioithieu/about-binh-dien/, accessed on February 28, 2020).

the nutrient granules, and some of them who have their paddy fields also test the product in their field.

Fourth, large-scale producers offer a warranty to retailers for losses caused by quality issues.[32] For example, retailers may be inspected and fined by government authorities. The warranty covers any such loss. Some producers have explicit warranty clauses in their sales contracts. Even if there is no legal foundation for warranty, retailers perceive it as an implicit norm, at least with major producers.

However, retailers are reluctant to deal with small-to-medium, new producers, even though these producers often make aggressive sales with attractive promotion policies. The retailers are concerned that these producers are not trustworthy; approvals, certificates, and licenses might be fake; and that these producers may not comply with the warranty provisions.

Competition among retailers. Retailer competition can be an essential channel to drive-out low-quality fertilizers since farmers can switch between to other retailers if they are unsatisfied with the purchased products. While the extent of competition depends on the location, many interviewed farmers indicated that they had access to several retailers. Retailers compete across several dimensions, such as an assortment of products, sales on credit, delivery services, and price. As many retailers offer sales on credit and deliver the fertilizers to each paddy field (mostly) for free, the assortment of products seems to be the critical dimension of differentiation. In deciding the product and brand to deal with, retailers listen to the voices of farmers. Some retailers mentioned that they make changes to the product because of farmers' complaints. We did not hear of information exchanges among retailers.

Perception of low-quality fertilizers. Perhaps because of the various initiatives described, all retailers covered by our interview survey mentioned that they had never encountered low-quality/fake fertilizer themselves. However, they tend to consider this problem to be prevalent in other provinces.

4.3. Farmers

Perception of low-quality fertilizers. Farmers also did not express concern about fake or low-quality fertilizers, even though they heard about the problem via newspapers or television. Most news on low-quality fertilizer problems comes from other provinces, and they do not seem to consider it an immediate problem. Accordingly, unlike in Africa, fertilizer quality does not seem to affect fertilizer adoption or usage. As we have discussed in Section 2.2., Vietnamese farmers apply fertilizers more intensively than in other Asian countries, and the government recommends a reduction in fertilizer use. Nguyen (2017) relates over-fertilization to low and unreliable fertilizer quality. However, none of the interviewed farmers mentioned fertilizer quality as a determinant of fertilizer use. Instead, the most likely cause of over-fertilization seems to be crop intensification due to the expansion of triple cropping (Arimoto et al., 2021), substitution for shortage of labor due to migration to off-farm employment, and poor knowledge on appropriate fertilizer usage.

Product choice. Farmers choose fertilizers based on several factors. The first layer of choice

[32] For example, Binh Dien company mentions on its website "Binh Dien is responsible for the quality at all stages of production, retail and usage." They have a system to confirm any problem found at the farmer level within 24 hours (according to the interview at Long An factory of Binh Dien Fertilizer Joint Stock Company on August 26, 2019 and website of the company [https://binhdien.com/gioithieu/about-binh-dien/, accessed on December 8, 2020]).

is the selection of retailers. The critical determinants of the choice of retailer seem to be the provision of credit and assortment of products. Farmers generally prefer retailers who sell fertilizers on credit and let them pay after harvest because they are usually short of cash during the cultivation period. The assortment of products is also crucial because farmers have preferences and loyalty toward certain brands. Distance to the retailer is less critical since retailers usually deliver fertilizers to paddy fields. Farmers do not express interest in whether the retailer holds the certificates required by Decree 108.

In contrast, major brands (producers and trademarks) are well recognized and controlled, and farmers rely on brands to select products. Note that, in principle, brands per se identify each product or producer (i.e., a product is manufactured by a specific producer and likely to hold consistent quality and characteristics over time), but not necessarily the quality. As there is no way for farmers to unveil the actual quality, they cannot precisely link quality with the brand. All they can do is infer the quality and form a belief.

Quality Assessment and Social Learning. The farmers' own experiences primarily form the belief in product quality. While fertilizers are considered noisy experience goods, many farmers indicated that they could infer the quality by observing the growth of the crop, change in leaf color, touch of granules, solubility, and country of origin for imported products.[33] The extent to which their quality assessments are accurate is questionable.[34] However, this anecdote indicates that farmers are trying their best to infer quality.

The belief in fertilizer quality and brands is also updated through social learning. It is common for farmers to exchange information about brands and retailers with other farmers. Local extension staff occasionally recommend certain brands to farmers. Cooperatives also recommend or even specify the brand when farmers engage in contract farming. Some farmers share feedback regarding their beliefs with retailers in terms of regular communication as well as complaints. As noted above, some retailers responded to consumers' voices by switching to different producers or products.

5. Discussion

5.1. Summary of fact findings

We find that fertilizer quality is fair on average, but the quality variability is substantial. The government is providing a standard package of regulations, which is updated constantly. Large-scale producers are differentiating their products through branding based on warranty and dealer certification. Retailers are competing along the dimension of product assortment and switch producers and brands depending on farmers' feedback. Farmers engage in both self-learning by observing crop growth and fertilizer characteristics as well as social learning through exchanging information. They sometimes feedback their assessment to retailers as complaints.

[33] Two farmers mentioned that they avoid buying fertilizers made in China.

[34] For example, Michelson, Fairbairn, Ellison, Maertens, and Manyong (2021) report that farmers rely on physical observable attributes to infer the quality of fertilizer in Tanzania but since these attributes are not correlated with nutrient content, they incorrectly understand this to be of low quality. Ashour et al. (2018) also report that farmers' beliefs on herbicide quality remain inaccurate. In our context, some farmers claim that fertilizer granules that do not dissolve immediately are of low quality. However, slow-release fertilizers are intentionally made to slow down dissolution and supply nutrients gradually.

5.2. Initiatives to control fertilizer quality

Given these observations, we identify the interaction of the three pillars as potential initiatives to mitigate the problem: government control, producers' branding, and learning and reputation building by farmers and retailers.

The first pillar, government control, is a primary and direct intervention. The Vietnamese government provides a standard set of regulations for quality disclosure (Dranove and Jin 2010). The regulations include: (i) licensing and certification at stages of production, distribution, retail, and inspection; (ii) mandatory quality labeling; and (iii) random inspections. During our interview, we have observed that producers and retailers comply with the regulations.

Meanwhile, the following issues hinder provincial governments from implementing efficient fertilizer management. Although Decree 108 is more comprehensive than the previous decrees, many other detailed regulations relating to fertilizer management remain unintegrated. For example, Decree 108 specifies sampling protocols, but it does not specify inspection procedures; the Ministry of Science and Technology provided the conditions on inspection in 2012 and 2017 (26/2012/TT-BKHCN, 12/2017/TT-BKHCN). [35] Furthermore, Decree 108 does not have provisions on penalties for violations. The local authorities must deal with it following three other Decrees, depending on the type of violation. [36]

In addition to such scattered regulations, the responsible agency for fertilizer management has not been unified at the provincial level, even though Decree 108 establishes the Ministry of Agriculture and Rural Development (MARD) as the sole responsible agency at the national level. According to our interview in An Giang province, both the provincial-level MOIT (i.e., Department of Industry and Technology (DOIT)) and the provincial-level MARD (i.e., Department of Agriculture and Rural Development (DARD)) have the authority to conduct fertilizer inspections. Furthermore, the provincial people's committee organizes and sends members to Steering Committee 389 in An Giang Province. [37] The DOIT, DARD, Steering Committee 389, the Department of Market Management, and the police also implement inspections independently. The frequency of inspection per retailer is restricted to once a year, and to avoid duplications of inspection, these agencies must identify uninspected retailers. [38]

Such complicated fertilizer-management policies can be further amplified through repeated policy changes. The government has already replaced Decree 108 with Decree 84 in November 2019 (84/2019/ND-CP). In conjunction with implementing the Law on Crop Production in 2018, this change consolidated many related but dispersed regulations that were complicated to

[35] Those instructions on inspection are applied not only to fertilizer but also to other products distributed in the market.

[36] The Decree 185 in 2013 (185/2013/ND-CP) deals with violations in production and sales activities in general, the Decree 119 in 2017 (119/2017/ND-CP) deals with violations in product quality in general and the Decree 55 in 2018 (55/2018/ND-CP) deals with violations in administrative procedures in the fertilizer sector. Each decree provides the form of punishment by type of violation (for example, amount of fine, revocation and suspension of certificate/approval for production, sales, and inspection).

[37] The committee is a substructure of the National Steering Committee 389. The National Steering Committee 389 was established under the Prime Minister's Decision 389 (389/2014/QD-TTg) in 2014 aiming to tackle smuggling, trade fraud, and counterfeiting.

[38] Interview of authorities in An Giang province (August 23, 2019).

administer.[39] Decree 84 was issued as implementing bylaws for the Law on Crop Production, but confusingly, Decree 84 itself came with various implementing bylaws. Therefore, the complexity of the fertilizer management system at the local government level has not been resolved; rather, it may have been exacerbated.

Thus, there seems to be room for improvement in coordinating the initiatives between different government entities, handling information on violations and communicating the testing results with the market, increasing the coverage and frequency of inspection, and improving compliance on the government side where cases of corruption on falsifying inspection results required to receive the approval of distribution have been reported.

The second pillar is the branding and product differentiation by the producers. Warranty is a well-known measure for producers to commit and signal quality under asymmetric information. Authentic dealer certification is another possible means of brand protection by eliminating counterfeits. Counterfeits can contaminate brands because packages or logos can be easily imitated. Authentic dealer certification assures that certified dealers sell genuine and warrantied products. This helps eliminate counterfeits because falsifying dealer certification is much more complex than imitating packages.[40] The current example of dealer certification described in section 4.2. does not yet have this functionality of eliminating counterfeits because it only accredits the agents' product knowledge. However, it does help agents to signal their close relationship with the producer and their knowledge.

The third pillar is learning and reputation building. Several complementary mechanisms facilitate the inference of the quality. First, farmers update their belief in quality through self-learning (self-experimentation) and social learning (exchange of information with others). One contextual difference between Vietnam and Africa is that Vietnamese farmers have a more extended rice cultivation and fertilizer use experience and use a more significant amount of fertilizer. Vietnamese farmers may be able to infer fertilizer quality better and reduce quality variability in the market.

Second, we find an alternative process of social learning, which could be referred to as "retailer-curated learning." Ordinary social learning is decentralized as each farmer decides which product to use based on the information exchanged within social networks. Learning is centralized in the retailer-curated learning because a retailer decides the product assortment. The decision is based on the retailer's "curation" of information about farmers' individual beliefs transmitted through the exit (farmers switching products or retailers) and voice (farmers' feedback). Given the competition between other retailers, incentives exist to pay careful attention to farmers' feedback and adjust the assortment by removing products that are likely to be of low quality. Retailers accumulate multiple quality signals and can better infer quality than individual farmers. The change in assortment will then be shared with producers, which gives them a chance to detect their quality problems and make improvements. Thus, retailers play a crucial role as an information "expert" in detecting the quality of goods and driving out low-quality goods (Biglaiser 1993; Biglaiser and Friedman 1994).[41]

[39] The report prepared by the Committee of Science, Technology and Environment, National Assembly on May 11, 2018 (858/BC-UBKHCNMT14).

[40] Producers can easily check and detect dealers falsifying a dealer certification. Consumers can also check if the dealer is certified through the publicized list of certified dealers.

[41] Moreover, inspection results from governments also provide reliable signals.

5.3. Policy implications

The Vietnamese experience provides several lessons. First, the government should install adequate regulations of licensing/certification, mandatory quality labeling, and random inspections. These government regulations are complementary for market initiatives. Producers' effort of providing high-quality products is not credible without these regulations. For noisy experience goods, producers' warranty itself cannot be trusted unless a third party verifies true quality. Producers can provide a warranty in any context, but their validity depends on the complementary institutions of third-party verifications.

Second, given adequate government regulations, the main driver in eliminating low-quality fertilizers is producers' branding. Government should support the protection of intellectual property rights such as trademarks, which is a premise for producers to maintain their brands. Authentic dealer certification and warranty seem to be effective strategies to protect their brands and eliminate counterfeits' contamination.

Third, speeding up learning of quality can help build reputations. A primary approach is to increase the frequency of random inspections. Accepting requests for inspection from farmers may also speed up the detection because suspicious products are more likely to be requested for testing.[42] Training and information diffusion by extension officers to farmers on methods to identify quality may be helpful to facilitate self-learning.

6. Conclusion

This paper aims to discover and describe the status of the problem regarding low-quality fertilizers in Vietnam. Our testing of 141 randomly selected fertilizers in the Mekong Delta Region indicates that the products carry nutrient levels as labeled on average but with large quality variability, and half of our samples have at least one nutrient that fails to meet the legal requirement. Our in-depth interviews find three initiatives against the problem of low-quality fertilizers: 1) government control through standard regulations; 2) producers' effort in maintaining product quality through branding; and 3) learning and reputation building by retailers and farmers. Overall, the average fertilizer quality is fair, and government and market initiatives are identified. However, an effort is needed to reduce the quality variability, and there is still room to improve the efficacy and implementation of government regulations.

The Vietnamese case suggests that both the government and market initiatives are essential to mitigate the problem of fertilizer quality. We highlight the importance of public regulations as they complement private initiatives: producers' branding and reputation-building rely on quality standards, labeling obligations, and third-party inspections. A set of regulations is needed to facilitate private efforts to produce high-quality goods.

Given the scope of our study, we do not have direct evidence that the observed initiatives are indeed effective in eliminating low-quality fertilizers. Rigorous policy evaluation is needed to understand "what works." However, these initiatives are standard and undertaken in many developed countries. While a thorough comparative study is needed, we believe that both direct government control and regulation and market competition are essential.

[42] The requested testing where anyone can request for nutrient testing at low cost was introduced in prewar Japan (Matsumoto and Sakane, 2017). Producers and retailers requested testing for signaling while buyers (mostly farmers associations) requested for quality verification.

Another limitation of our study is that our sampling is limited by sample size, regional coverage, and distribution channels. We note that our sample focuses only on an important portion of the overall market, given that we exclude major producers' products. However, it seems natural to infer that the quality of products by these excluded producers is not worse than that of our minor producers. Future studies should test this hypothesis. We also note that direct sales by local small and medium producers, a channel with the highest risk of quality problems, are not covered in our sample. While existing information suggests that this channel accounts for only a small share of the total market, further study is needed to uncover the overall picture in Vietnam.

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Appendix. Intentional or incompetent?

An important question is whether the quality deviation is intentional or merely because producers are incompetent in their production and quality management. We assess this question by focusing on a particular possible cause of unintentional variations in deviation rates: the inadequate stirring of straight fertilizers of different nutrients during the production process of mixed fertilizers and segregation of nutrient granules during transportation. In these cases, even if a producer used an appropriate quantity of nutrients in total,[43] the composition of nutrients might vary across different bags; for example, some bags may contain too much nitrogen, whereas other bags may contain too little. Similar compositional variation might occur due to the segregation of nutrient granules *within a bag* of mixed fertilizers during transportation or storage; heavier granules fall under lighter granules within each bag.

The key idea behind detecting these unintentional quality deviations is that they cause *compositional variations* between nutrients, even if the producers used an appropriate quantity of nutrients in total. That is, some nutrients might be in excess, whereas other nutrients are short. However, such compositional variations are more likely to occur for mixed fertilizers, which simply mix straight fertilizers of different nutrients but are unlikely for complex fertilizers in which three nutrients are compounded in one granule. Thus, if inadequate stirring or careless transportation are the leading causes of quality diversity, we expect an apparent negative correlation of deviation rates between nutrients *within* a sample for mixed fertilizers but not for complex fertilizers. To this end, we examine the joint distributions of multiple nutrients contained, unlike the existing studies that solely focus on the distribution of nitrogen (Ariga et al. 2019; Bold et al. 2017; Michelson, et al. 2021).

Mixed vs. complex fertilizers

Table A4 compares the quality of mixed and complex fertilizers by regressing the fertilizer quality on the dummy for complex fertilizers. Compared to mixed fertilizers, the deviation rate for complex fertilizers is low in nitrogen (-2.8%), almost consistent in phosphate (-0.8%), and high in potassium (13.2%). Columns 5 and 6 regress the complex fertilizer dummy on the sub-standard dummy. Complex fertilizers have a lower probability of being sub-standard. These results suggest that the quality of complex fertilizers is better than that of mixed fertilizers.

Deviation rates for complex fertilizers might be lower than mixed fertilizers because producing complex fertilizers implies that the producer has more advanced skills and technologies, and mixed fertilizers have a risk of inadequate stirring of granules with different nutrients during production, storage, and transportation (discussed in detail below).

If poor stirring or transportation is the cause of quality deviation, we expect: 1) deviation rates to be independent between three nutrients within a sample (i.e., if the quality deviation is intentionally caused by adulteration, we expect *all* nutrients to be *jointly* diluted); 2) negative correlation of deviation rates between nutrients *within* a sample (i.e., if one nutrient content is in excess, then we should observe shortage for others); 3) such correlation should be observed for mixed fertilizers but not for complex fertilizers (because three nutrients are compound in one granule); and 4), even if we observe quality variation in our samples, the deviation rates should

[43] Our data are consistent with this assumption as total deviation rates (fraction of actual content of all three nutrients to total labeled level) are almost zero with little variation (Table A4).

be close to zero at the *production lot* level, on average. Predictions 1) to 3) can be tested with our samples, whereas the last prediction cannot be tested without a sufficient sample size from each production lot.

We begin by comparing the distribution of the deviation rates between the nutrients within a sample. For each sample i, we first calculate the mean and the standard deviation of the three deviation rates, one for each nutrient (N, P, and K). We then take the average over the sample of these means and standard deviations, respectively, by mixed or complex fertilizers. The mean of mean deviation rates is lower for mixed fertilizers than for complex fertilizers (-2.8% vs. 3.2%), and the mean of standard deviations are larger for mixed fertilizers than for complex fertilizers (18.4 vs. 12.0%). These results indicate that mixed fertilizers are, on average, of lower quality, and the quality variability between nutrients within a sample is larger than that of complex fertilizers.

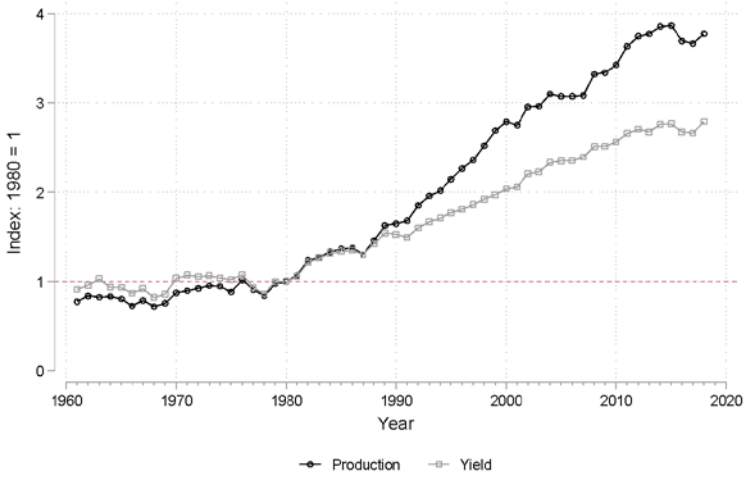
complex	stats	mm_NPK~v	sd_NPK~v
0	mean	-2.83561	18.39888
	sd	12.95538	17.2831
1	mean	3.197552	12.01277
	sd	5.754352	9.988616
Total	mean	-2.250303	17.77933
	sd	12.55534	16.79614

Figure A3 plots the deviation rates between the three sets of binary combinations of nutrients by complex and mixed fertilizers. Table A5 reports the estimation results of regressing the deviation rates of phosphate (P) or potassium (K) on deviation rates of the remaining nutrients, dummy for complex fertilizer, and their interaction terms.

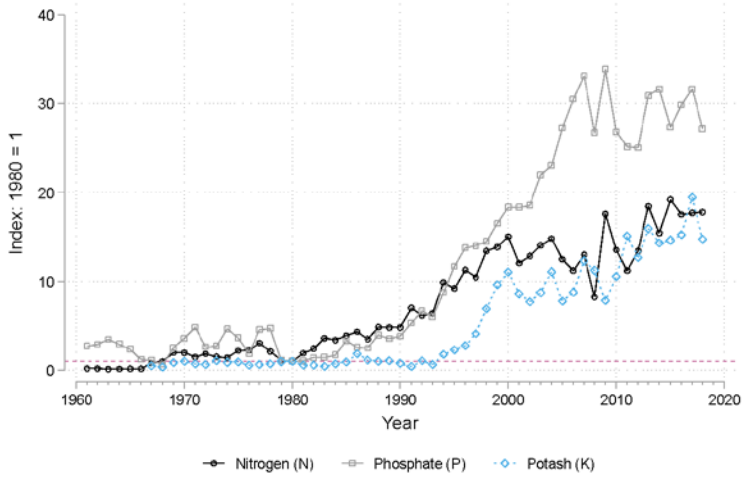
The relationship between deviation rates is complex. We observe a significantly negative correlation between the deviation rates of nitrogen (N) and potassium (K) for mixed fertilizers in Panel (b), and a negative correlation between the deviation rates of K and phosphate (P) for complex fertilizers in Panel (c). These observations are confirmed in Table A5, where the coefficients of the deviation rate of nitrogen in the regression of the deviation rate of potassium are negative and significant (columns 4-6), and the coefficient of the interaction terms of the complex fertilizer dummy and the deviation rate of potassium on the deviation rate of phosphate are negative and significant (column 3).

The negative correlation between N and K for mixed fertilizers is consistent with the "substitution" hypothesis (Prediction 2) due to poor stirring or segregation of granules. However, the negative association between the deviation rates of K and P for complex fertilizers is contrary to the above prediction. In any case, we did not find clear evidence of production failure or problems during transportation.

In summary, the assessment of the distributional patterns of deviation rates suggests that the nutrient content may be intentionally lowered. We did not find evidence that large quality variation is due to poor stirring or segregation of nutrient granules during transportation for mixed fertilizers.



(a) Production and yield of paddy (1980 = 1)



(b) Fertilizer usage (1980 = 1)

Figure 1**.** Paddy production, yield and fertilizer usage

Source: FAOSTAT.

Note: Production based on "Crops: Production: Rice, paddy (tons)." The yield is based on "Crops: Yield: Rice, paddy (kg/ha)." Fertilizer usage: “Fertilizers indicators: Use per area of cropland” for nutrient nitrogen N (total) (kg/ha), nutrient phosphate P2O5 (total) (kg/ha), and nutrient potassium K2O (total) (kg/ha).

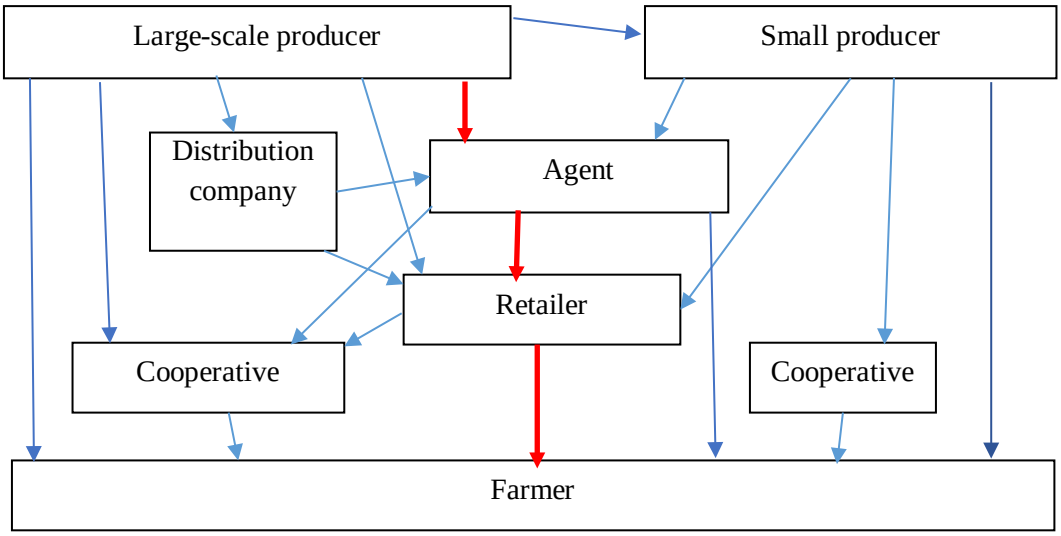


Figure 2. Fertilizer distribution channels in Vietnam

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

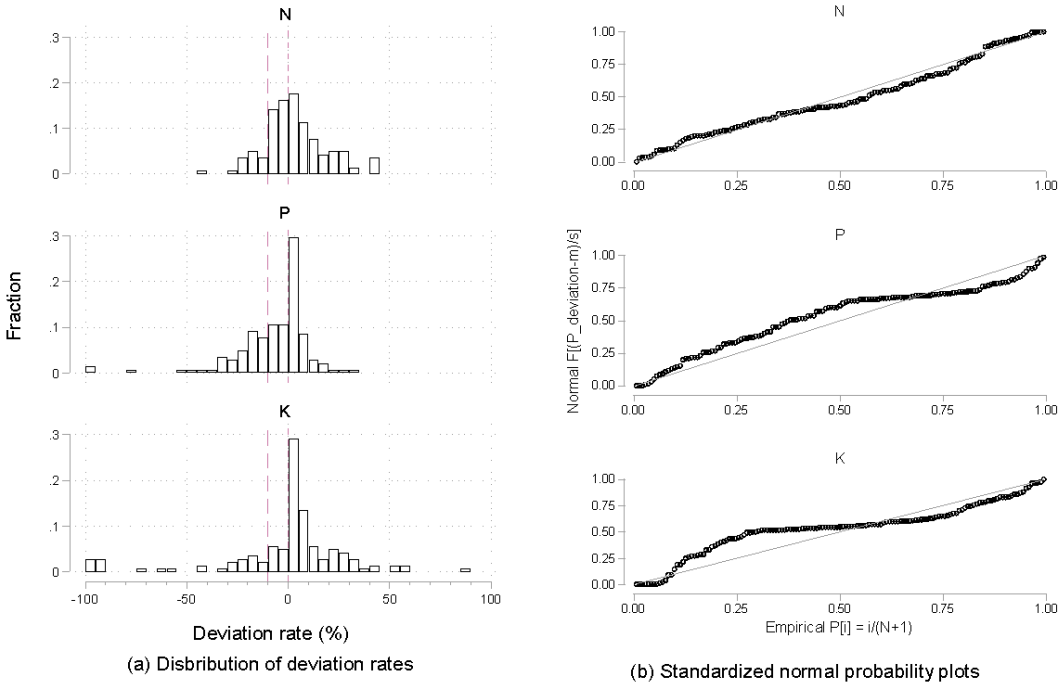


Figure 3**.** Distribution of deviation rates by nutrient

Note: Panel (a) depicts histograms of the distribution of deviation rates. Panel (b) shows the standardized normal probability plots. The dashed vertical lines in Panel (a) at −10% show the legally acceptable level of the deviation rate.

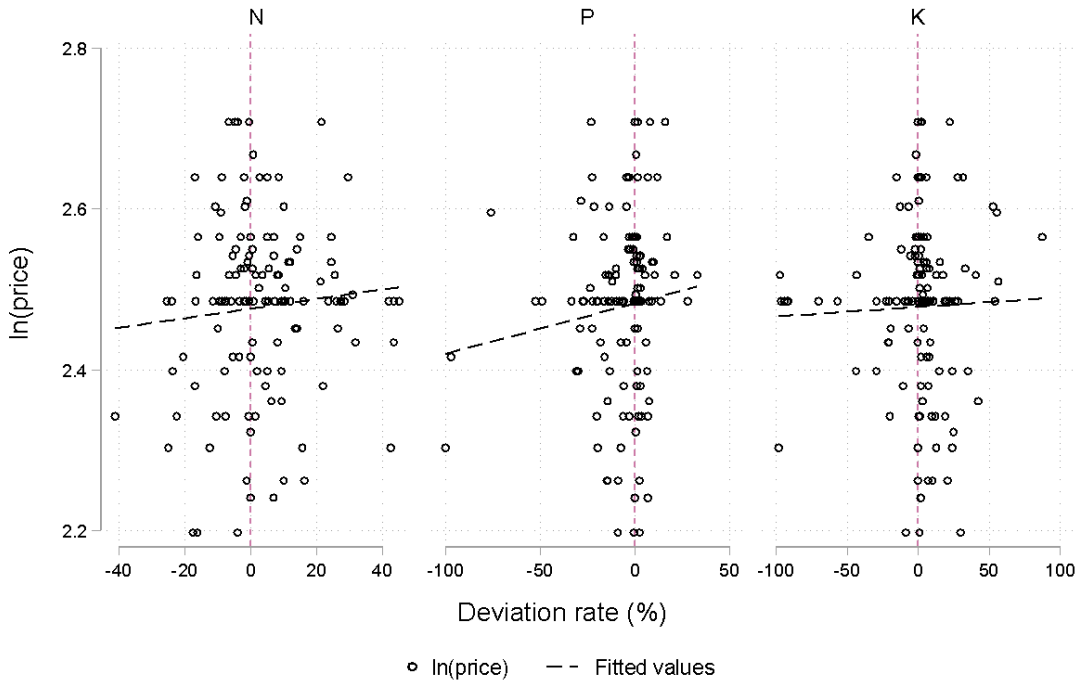


Figure 4. Price and deviation rate

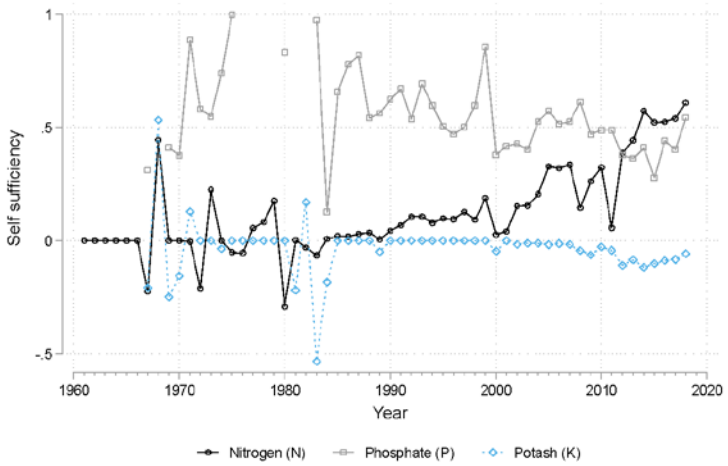


Figure A1. Self-sufficiency of fertilizers

Source: FAOSTAT.

Note: Self-sufficiency is defined as (agricultural use – import) / agricultural use, where agricultural use and imports are reported in quantity (tons). Based on "Fertilizers by Nutrient: Agricultural Use" and "Fertilizers by Nutrient: Agricultural Use: Import Quantity" for nutrient nitrogen N (total) (tonnes), nutrient phosphate P2O5 (total) (tonnes), and nutrient potassium K2O (total) (tonnes).

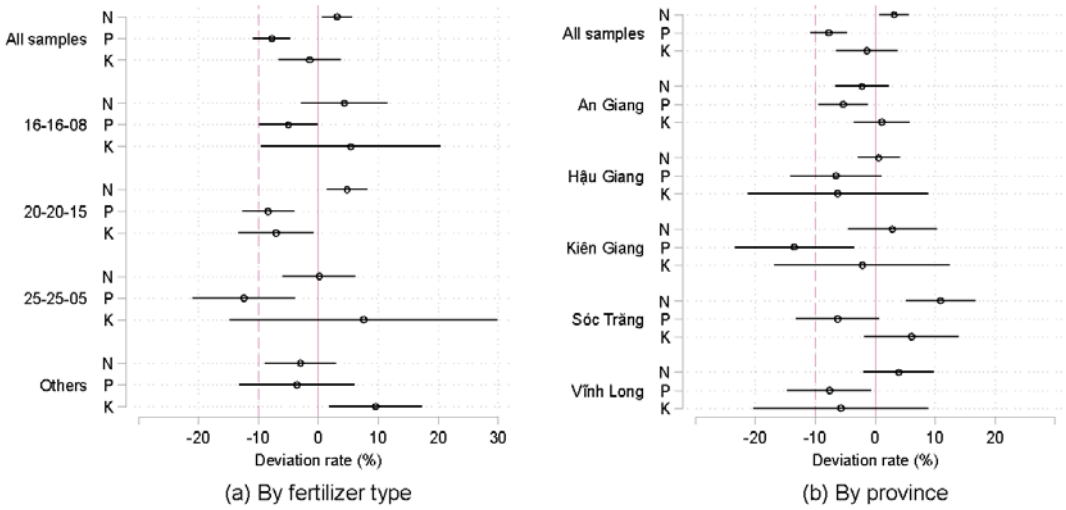


Figure A2. Mean deviation rates by fertilizer type and province

Note: 95% confidence intervals are calculated based on robust standard errors. -10% is the legally acceptable lower bound.

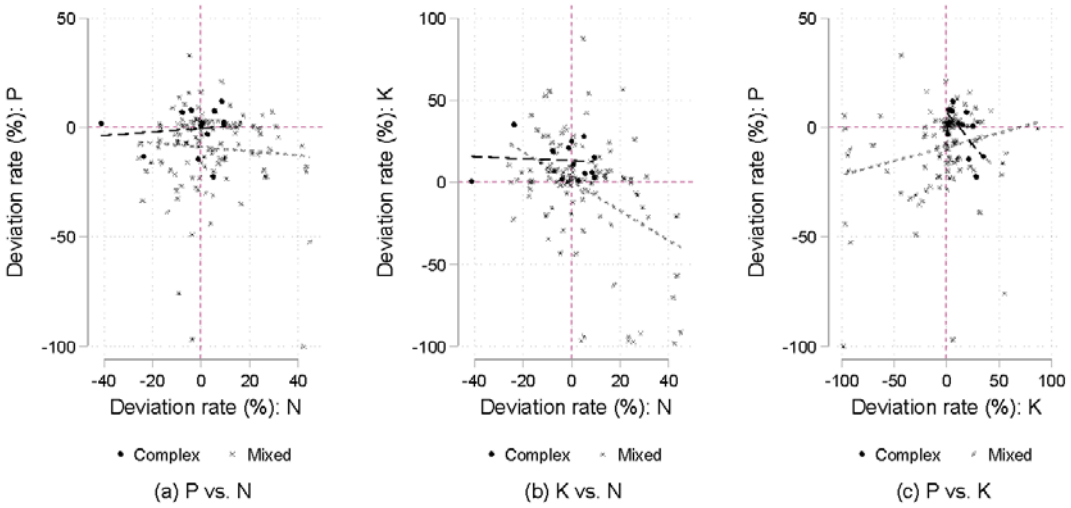


Figure A3. Correlation of deviation rates between P and K

Table 1. Newspaper reports on low-quality or fake fertilizers

Reference	The ratio of low-quality/fake fertilizer	Evidence	Information source
Công (2009)	435 (47.18%) out of 922 samples of fertilizer products not meeting the standards.	The inspection was conducted in 4434 fertilizer producers and distributors in 22 southern provinces in 2008.	Aggregate data of 22 provinces (incomplete)
Quang (2010)	419 (48.8%) out of 859 samples did not match the ingredients shown on the package. In particular, 58% of the inorganic fertilizer samples (mainly NPK) did not match the labeled ingredients.	The sample tests were conducted in 17 southern provinces in 2009.	Aggregate data reported by 17 provinces
Nguyễn (2013)	Up to 41% of the tested samples showed that all three factors of NPK failed to match the labeled ingredients.	The tests of samples were taken from several producers and distributors nationwide in 2011.	Ministry of Industry and Commerce
Khánh (2017)	69 (over 40%) out of 158 samples did not match the labeled ingredients.	The tests of 158 samples of fertilizer products in Tra Vinh Province in 2014.	Department of Industry and Commerce of Tra Vinh Province
Minh (2018) Phan (2018)	306 (21.5%) out of 1420 fertilizer and pesticide samples were found in violation.	The inspection on 1420 fertilizer and pesticide products was conducted nationwide in the first quarter of 2018.	The National Steering Committee 389
Hoàng (2019)	12 (24%) out of 50 fertilizer samples were found in violation. Ten samples did not meet the ingredients shown on the package, and two samples were fake products.	The inspection of 50 fertilizer samples in Long An Province was conducted in the first half of 2019.	The Department of Market Management of Long An Province

Source: Prepared by the authors.

Table 2. Deviation rates

	n	Mean	S.D.	*p*-value
Deviation rate (%)				
N (nitrogen)	141	3.197	15.147	0.013 *
P (phosphate)	141	-7.753	18.695	0.000 ***
K (potash)	141	-1.379	31.143	0.600
Total (N+P+K)	141	-0.025	0.107	0.000 ***
Sub-standard (Deviation rate < -10%)				
At least one of NPK	141	0.489	0.502	0.000 ***
N (nitrogen)	141	0.135	0.343	0.000 ***
P (phosphate)	141	0.333	0.473	0.000 ***
K (potash)	141	0.206	0.406	0.000 ***
Total (N+P+K)	141	0.000	0.000	
Sub-standard (Deviation rate < -50%)				
At least one of NPK	141	0.092	0.290	0.000 ***
N (nitrogen)	141	0.000	0.000	
P (phosphate)	141	0.028	0.167	0.045 *
K (potash)	141	0.078	0.269	0.001 ***
Total (N+P+K)	141	0.000	0.000	

Note: *p*-value reports the univariate regression against the constant.

Table 3. Diagnosis on the distributions of deviation rates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	n	Mean	S.D.	Skewness	Kurtosis	Prob. Skewness	Prob. Kurtosis	Joint adj chi2(2)	Joint Prob>chi2
N: %deviation	141	3.197	15.147	0.48	3.653	0.020	0.110	7.350	0.025
P: %deviation	141	-7.753	18.695	-2.093	10.443	0.000	0.000	59.470	0.000
K: %deviation	141	-1.379	31.143	-1.327	6.117	0.000	0.000	33.380	0.000

Table 4. Correlation between price and quality

	(1) N	(2) P	(3) K	(4) N+P+K	(5) At least one sub-standard (<-10%)	(6) At least one sub-standard (<-50%)
Deviation rate (%)	0.000598	0.000629	0.000119	0.132		
	(0.000576)	(0.000467)	(0.000232)	(0.0763)		
Sub-standard (dummy)					-0.0276	-0.00293
					(0.0193)	(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 dependent variable is the log (price). The explanatory variable for columns 1–4 is the deviation rate, measured as a percentage [0-100]. The explanatory variable for columns 5 and 6 is a sub-standard dummy, indicating that at least one nutrient contains 10% (50%) less than the labeled level. Robust standard errors are reported in parentheses. $* p < 0.05, ** p < 0.01, *** p < 0.001$.

Table 5. Major license and certificates on fertilizers

License/certificate	Required for	Requirements
Approval of distribution (công nhận lưu hành)	Distributing fertilizer product	Issued by the Department of Plant Protection (Cục Bảo về thực vật) of the Ministry of Agriculture and Rural Development (MARD) (hereafter, MARD-DPP) The approval is valid for five years and must be re-approved three months before expiry. Field tests are required before approval, and the test procedure is specified in detail. The tests are only allowed to be conducted by organizations that meet certain conditions and are accredited by the MARD-DPP.
Fertilizer producer license (Giấy chứng nhận đủ điều kiện sản xuất phân bón)	Production of fertilizer	Issued by MARD-DPP. All producers must meet the specified criteria regarding production facilities and staff.
Fertilizer retailer certificate (Giấy chứng nhận đủ điều kiện buôn bán phân bón)	Fertilizer retailer	Issued by the Sub-Department of Plant Protection, Department of Agriculture and Rural Development at the provincial level. The requirement for the retailer certificate includes certain sales facilities and the mandate that a person responsible for selling fertilizers must obtain the *fertilizer specialist certificate*.
Fertilizer specialist certificate (Giấy chứng nhận bồi dưỡng chuyên môn về phân bón)	Sales manager of fertilizer at a retailer	Finish a 3-day training course, unless he or she has a specific educational background in particular fields such as horticulture, plant protection, soil and fertilizer, or agronomy.
Certification of fertilizer sampling (Giấy chứng nhận tập huấn lấy mẫu phân bón)	Sampling specialist	Finishing a 5-day training course.

Table A1. Major fertilizer producers in Vietnam

Name of company	Group	Products	Capacity (thousands ton/ year)	Brand	Established
Habac Nitrogenous Fertilizer & Chemicals Company Limited	Vinachem	Urea	500	Ha Bac	before *Doi Moi*
Binh Dien Fertilizer Joint Stock Company	Vinachem	NPK	1050	Dau Trau	before *Doi Moi*
Ninh Binh Introgenous Fertilizer Ltd. Company	Vinachem	Urea	560	Ninh Binh	after 2010
Southern Fertilizer Corporation	Vinachem	NPK Superphosphate Organic	600	Con O	before *Doi Moi*
Van Dien Phosphate Corporation	Vinachem	FMP NPK	300 150	Van Dien	before *Doi Moi*
Lam Thao Phosphate and Chemical JSC	Vinachem	NPK Superphosphate Axit sunfuric H2SO4 FMP	700 850 280 300	Lam Thao	before *Doi Moi*
Ninh Binh Phosphate Fertilizer Joint Stock Company	Vinachem	FMP NPK	300 200	NIFERCO	before *Doi Moi*
Can Tho Fertilizer & Chemical Joint Stock Company	Vinachem	NPK Organic	300 40	Co Bay	before *Doi Moi*
DAP-VINACHEM Joint Stock Company	Vinachem	DAP	330	DAP	late 2000s
DAP2-VINACHEM Joint Stock Company	Vinachem	DAP	330	DAP Lao Cai	late 2000s
PETROVIETNAM Fertilizer and Chemicals Corporation (PVFCCo)	PVN	Urea NPK MOP	1000	Phu My	early 2000s
PETROVIETNAM Ca Mau Fertilizer Joint Stock Company	PVN	Urea	815	Ca Mau	after 2010

Source: Website of each company (accessed on December 17, 2019)

Table A2. Descriptive statistics

	n	Mean	S.D.
Deviation rate (%)			
N (nitrogen)	141	3.197	15.147
P (phosphate)	141	-7.753	18.695
K (potash)	141	-1.379	31.143
Total (N+P+K)	141	-0.025	0.107
Fertilizer type			
16-16-08	141	0.142	dummy
20-20-15	141	0.610	dummy
25-25-05	141	0.121	dummy
Others	141	0.128	dummy
Province			
An Giang	141	0.220	dummy
Hậu Giang	141	0.163	dummy
Kiên Giang	141	0.184	dummy
Sóc Trăng	141	0.191	dummy
Vĩ nh Long	141	0.241	dummy
	s		
Price (1000VND/kg)	131	11.986	1.305
Complex (mixed) fertilizer dum	134	0.097	dummy

Note: Sample sizes for price and complex fertilizer are small due to missing price information and sample image (photo) data.

Table A3. Mean deviation rates (overall, by fertilizer type, by province)

	(1) N	(2) P	(3) K	(4) N+P+K
All samples	3.197*	-7.753***	-1.379	-0.0245**
	(1.276)	(1.574)	(2.623)	(0.00899)
By fertilizer type				
16-16-08	4.344	-4.969*	5.450	0.00840
	(3.438)	(2.317)	(7.097)	(0.0206)
20-20-15	4.820**	-8.364***	-7.022*	-0.0320*
	(1.742)	(2.212)	(3.221)	(0.0127)
25-25-05	0.141	-12.40**	7.553	-0.0489*
	(2.814)	(3.975)	(10.38)	(0.0237)
Others	-2.948	-3.538	9.553**	-0.00215
	(2.765)	(4.495)	(3.644)	(0.0151)
By province				
An Giang	-2.173	-5.301*	1.109	-0.0261
	(2.212)	(2.048)	(2.282)	(0.0157)
Hậu Giang	0.620	-6.543	-6.205	-0.0376
	(1.712)	(3.679)	(7.259)	(0.0193)
Kiên Giang	2.865	-13.45**	-2.152	-0.0492
	(3.609)	(4.857)	(7.092)	(0.0295)
Sóc Trăng	10.92***	-6.267	6.067	0.0285*
	(2.825)	(3.407)	(3.832)	(0.0129)
Vĩ nh Long	3.954	-7.627*	-5.706	-0.0375*
	(2.889)	(3.475)	(7.217)	(0.0187)

Note: This table reports the mean deviation rates for each nutrient indicated in columns. Each cell reports the mean deviation for the category indicated in rows. Robust standard errors are reported in parentheses. $* \, p < 0.05, \; ** \, p < 0.01, \; *** \, p < 0.001$.

Table A4. Comparison between mixed vs. complex fertilizers on quality

	All samples			Complex fertilizers			Mixed fertilizers			Complex vs. mixed		
	n	Mean	S.D.	*n*	Mean	S.D.	*n*	Mean	S.D.	Difference	S.E.	*p*-value
Deviation rate (%)												
N (nitrogen)	141	3.197	15.147	13	-2.837	14.571	121	3.751	15.358	-6.588	(4.155)	0.115
P (phosphate)	141	-7.753	18.695	13	-0.788	10.062	121	-9.358	19.244	8.570	(3.222)	0.009 **
K (potash)	141	-1.379	31.143	13	13.218	11.513	121	-2.900	33.027	16.12	(4.316)	0.000 ***
Total (N+P+K)	141	-0.025	0.107	13	0.015	0.063	121	-0.033	0.110	0.0475	(0.0196)	0.017 *
Sub-standard (Deviation rate < -10%)												
At least one of NPK	141	0.489	0.502	13	0.308	0.480	121	0.529	0.501	-0.221	(0.137)	0.108
N (nitrogen)	141	0.135	0.343	13	0.154	0.376	121	0.140	0.349	0.0134	(0.106)	0.900
P (phosphate)	141	0.333	0.473	13	0.231	0.439	121	0.364	0.483	-0.133	(0.126)	0.292
K (potash)	141	0.206	0.406	13	0.000	0.000	121	0.231	0.423	-0.231	(0.0386)	0.000 ***
Total (N+P+K)	141	0.000	0.000	13	0.000	0.000	121	0.000	0.000	0		
Sub-standard (Deviation rate < -50%)												
At least one of NPK	141	0.092	0.290	13	0.000	0.000	121	0.107	0.311	-0.107	(0.0284)	0.000 ***
N (nitrogen)	141	0.000	0.000	13	0.000	0.000	121	0.000	0.000	0		
P (phosphate)	141	0.028	0.167	13	0.000	0.000	121	0.033	0.180	-0.0331	(0.0164)	0.046 *
K (potash)	141	0.078	0.269	13	0.000	0.000	121	0.091	0.289	-0.0909	(0.0263)	0.001 ***
Total (N+P+K)	141	0.000	0.000	13	0.000	0.000	121	0.000	0.000	0		

Note: Robust standard errors are reported in parentheses. $* \, p < 0.05$, $** \, p < 0.01$, $*** \, p < 0.001$.

Table A5. Correlation of deviation rates between nutrients

	(1) P: %deviation	(2) P: %deviation	(3) P: %deviation	(4) K: %deviation	(5) K: %deviation	(6) K: %deviation
N: %deviation	0.0433	0.0217	0.0242	-0.814***	-0.801***	-0.864***
	(0.108)	(0.106)	(0.116)	(0.182)	(0.189)	(0.196)
K: %deviation	0.137	0.124	0.133			
	(0.0755)	(0.0755)	(0.0765)			
P: %deviation				0.318	0.305	0.327
				(0.174)	(0.185)	(0.189)
Complex fertilizer=1		6.710	16.10***		8.228	9.214**
		(3.598)	(3.020)		(5.149)	(3.453)
Complex fertilizer=1 # N: %deviation			0.0184			0.864**
			(0.145)			(0.281)
Complex fertilizer=1 # K: %deviation			-0.717***			
			(0.200)			
Complex fertilizer=1 # P: %deviation						-1.095***
						(0.251)
Constant	-7.702***	-9.079***	-9.062***	3.688	2.957	3.398
	(1.539)	(1.728)	(1.751)	(2.228)	(2.657)	(2.678)
Observations	141	134	134	141	134	134
R-squared	0.047	0.060	0.077	0.202	0.209	0.230

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

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. $* p < 0.05$, $** p < 0.01$, $*** p < 0.001$.