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Heterogeneous returns to chemical fertilizer at the intensive margins: Insights from Nepal

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ABSTRACT

Increased fertilizer use is considered important for agricultural development in low-income countries. Promoting increased use of chemical fertilizer by lowering its price may be ineffective if demand is price inelastic. In theory, the price elasticity of demand depends on the returns to its use, but the evidence is scarce. Furthermore, while returns are often estimated for small changes in chemical fertilizer use, returns to larger changes in its use (intensive margins) are less understood. Through the inter-zonal comparisons in Nepal, we provide indicative evidence that greater returns to chemical fertilizer are associated with greater price elasticities of demand. Moreover, the evidence suggests that returns at the intensive margins, rather than returns to small changes, may largely account for inter-zonal differences in returns to chemical fertilizer within Nepal. The results suggest that better understanding the returns at the intensive margins is critical for effective agricultural inputs policies in developing countries.

1. Background

The increased use of chemical fertilizer is considered an important process of agricultural development. In theory, returns to chemical fertilizer use are an important determinant of fertilizer use intensity in low-income countries. Despite the growing literature, a knowledge gap still exists regarding the returns to chemical fertilizer at the "intensive margins" (returns from a large change in chemical fertilizer use), as they can differ considerably from returns to a small change in chemical fertilizer use, which are often estimated by conventional parametric models in the literature. Agricultural technologies in developing countries including fertilizer can exhibit high marginal returns to small increases in their use but also low overall returns if the marginal returns diminish rapidly at the intensive margins (Banerjee and Duflo, 2011, p.215). In such cases, the elasticity[1] of demand for chemical fertilizer relative to its price changes ("price elasticity" hereafter) may be generally low. Such hypotheses are consistent with the seemingly puzzling patterns in many developing countries where the marginal returns to chemical fertilizer can be high (for example, Duflo et al., 2008 in Kenya) but the effects[2] of interventions aimed at increasing chemical fertilizer use or reducing food prices by reducing chemical fertilizer prices (such as subsidies) are often limited (Jayne and Rashid, 2013; Takeshima and Liverpool-Tasie, 2015).[3] However, the estimation of returns at the intensive margins has been challenging because chemical fertilizer use decision is often endogenous to the returns, and conventional parametric models are more suitable for estimating the returns to small changes in the variable of interest conditional on other covariates.

We aim to partly fill this gap by estimating the returns to chemical fertilizer at the intensive margins, using the Generalized Propensity Score Matching (GPSM) method developed by Hirano and Imbens (2004). GPSM allows the construction of counterfactuals for a range of chemical fertilizer use intensity, from which one can estimate the returns at the intensive margins. We apply our

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[1] Our interest is in the "intensity" of chemical fertilizer uses, therefore we use the term "elasticity" to describe the actual quantity of changes in demand, rather than percentage changes, as is sometimes defined in the literature.as

[2] The "effects" we refer to here are the effects on increasing adoption and consumption of chemical fertilizer, although our broad objective is to inform how the productivity/income effects of chemical fertilizer are linked with the price elasticity of chemical fertilizer demand.

[3] The pathways of such effects are heterogeneous. In some cases, while subsidies effectively reduce the prices of chemical fertilizer, such price reductions may not benefit the correct group of farmers whose demand is more price elastic, due to inappropriate targeting. In some other cases, the effort simply failed to reduce the prices, because of, among other reasons, leakages and rent-seeking activities.

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analyses to Nepal, which is an ideal case. Nepal consists of diverse agroecological belts, Hills and Mountains with rugged terrain, and Terai with flat terrain. Worldwide, countries with rougher terrains are associated with lower uses of chemical fertilizer relative to the uses of organic fertilizer like manure (Takeshima et al., 2016 Table 3.1). In addition, recent mechanization growth in the Terai relative to the Hills/Mountains might have led to sharper differences in such returns, due to the changing returns to scale in production (Takeshima, in press). Comparing Terai with Hills/Mountains in Nepal therefore offers a particularly relevant setting for examining how returns vary at the intensive margins. We show that higher returns to chemical fertilizer at the intensive margins are associated with more elastic demand for chemical fertilizer.

Importantly, returns in our analyses are measured on incomes, rather than on physical outputs such as yield, which are also commonly studied in the literature. Unlike the returns on yield, returns on incomes better capture the opportunity costs of chemical fertilizer use by incorporating the associated changes in other factors like labor use and thus changes in income earnings outside farming. This factor is particularly important in developing countries, where rising labor costs and growing mechanization are altering the relations between labor and non-labor use in smallholder farming (Otsuka et al., 2016). In addition, while our data provide detailed information about household expenditures which can be used to proxy incomes relatively accurately, they do not provide sufficiently detailed agronomic information required for correctly assessing the returns on yield. While the richer understanding of the returns to chemical fertilizer use requires not only the returns on incomes but also careful analysis of physical returns on yield, the former can still shed light on the important patterns of heterogeneity in returns to chemical fertilizer.

This paper is structured in the following way; Section 2 summarizes the knowledge gap in the relevant literature; Section 3 presents primary data and the background trends on chemical fertilizer prices and consumption in Nepal; Section 4 describes the empirical framework; Section 5 presents descriptive statistics; Section 6 summarizes the results, while Section 7 concludes.

2. Price elasticity of chemical fertilizer demand and returns to chemical fertilizer use at the intensive margins

We aim to partly fill the knowledge gap that relates to various strands of growing literature of fertilizer in developing countries. Here, we briefly describe them.

The literature suggests that chemical fertilizer price is one of the significant determinants of its use in developing countries (Ahmed, 1995; Xu et al., 2009; Takeshima and Nkonya, 2014; Liverpool-Tasie, 2017). Favorable price ratios between chemical fertilizer and rice in Asia relative to Africa is consistent with higher chemical fertilizer intensity in the former region (Otsuka and Kalirajan, 2006). However, in some countries, the demand for chemical fertilizer may be inelastic to its price, which in theory can cause subsidies to crowd out demand for commercial fertilizer (Takeshima and Nkonya, 2014). Price elasticity may be reduced if the demand is constrained by non-price factors, such as untimely availability (Abrar et al., 2004), credit constraints, knowledge, risks, or market access (Lamb, 2003; Dercon and Christiaensen, 2011). Broadly, however, low price elasticity can still be due to the low overall returns from chemical fertilizer use, which discourage private-sector innovations from overcoming market failures for these non-price factors. Few studies assess if the price elasticity of chemical fertilizer demand is associated with returns from its use.

The literature on returns to fertilizer mostly focuses on returns on yields of specific crops (Yanggen et al., 1998; earlier rice literature like Herdt and Capule, 1983; Kikuchi et al., 2003), rather than economic returns on incomes. Where economic returns are estimated, they are often approximated by value-cost-ratios (VCR), which are calculated by applying value-ratios to returns on yields. Commonly estimated VCR may not always account for the effects of the change of other inputs like labor, and thus the effects on overall incomes.

Studies that do assess the effects on incomes generally focus on the binary aspect of the adoption (whether adopting chemical fertilizer or not, regardless of the intensity of the adoption) (for example, Mason et al., 2017). When assessing the returns to chemical fertilizer use intensity rather than a binary aspect of adoption, the literature typically applies parametric forms to approximate the return curves. Studies estimating output-to-nutrient ratio or VCR (Yanggen et al., 1998; Kelly, 2006; Morris et al., 2007; Liverpool-Tasie, 2017) often assume linearity, i.e., marginal returns are constant regardless of chemical fertilizer use intensity. While the linearity assumption may be appropriate for assessing the returns to a small change in chemical fertilizer use, it may be too restrictive for characterizing the returns at the intensive margins. Some studies extend the analyses by employing natural logarithm or square terms of chemical fertilizer use to allow marginal returns to vary at different chemical fertilizer use intensity (Herdt and Capule, 1983; Kikuchi et al., 2003; Marenya and Barrett, 2009; Sheahan et al., 2013). However, they are still restrictive and can deviate considerably from true return curves at levels that are very different from sample means. Furthermore, allowing flexible functional forms in parametric specifications is difficult given the potential endogeneity of chemical fertilizer use with incomes, which is not addressed commonly in the literature.

Lastly, examining returns from the intensive margins contributes to the literature on the relationship between agricultural productivity and farm size. While earlier literature often suggests an inverse relationship (Chayanov, 1965; Schultz, 1965), recent studies suggest that this pattern has been reversed (Collier and Dercon, 2014), particularly in Asia with growing mechanization (Otsuka et al., 2016; Yamauchi, 2016). However, few studies offer insights into how such productivity-size relationships may relate to the heterogeneity in the returns to chemical fertilizer.

3. Dataset, trends of prices and uses of chemical fertilizer

Our analyses primarily rely on the Nepal Living Standards Survey data (NLSS), conducted in 1995, 2003, and 2010 by Nepal's Central Bureau of Statistics (CBS). The NLSS were collected through multistage stratified random sampling methods in each round. Specifically, six strata were defined across Nepal, consisting of urban and rural areas in each of Terai, Hills, and Mountains, and enumeration areas (EAs) were randomly selected from each stratum.[4] In the NLSS 1995, 275 wards were used as EAs, from which 3388 households were sampled. In the NLSS 2003, 4008 cross-section samples were randomly selected from 800 EAs, and 1232 panel samples were randomly selected from the NLSS 1995. In the NLSS 2010, 5988 cross-section samples were randomly selected from 500 EAs redefined from the 800 EAs in the NLSS 2003, and 1032 panel samples were randomly selected from the NLSS 2003. Within each EA, households were randomly selected for the interview (Nepal CBS, 1996, 2004, 2011a). In the NLSS, cross-sectional samples alone are representative (Nepal CBS, 2004, 2011b).

[4] For the NLSS 1995, only the Hills region was further stratified into urban and rural.