Food Policy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Food Policy

journal homepage: www.elsevier.com/locate/foodpol

Effects of tractor ownership on returns-to-scale in agriculture: Evidence from maize in Ghana

Hiroyuki Takeshima[a,*], Nazaire Houssou[b], Xinshen Diao[a]

[a] International Food Policy Research Institute, 1201 Eye Street, NW, Washington, DC, United States
[b] International Food Policy Research Institute, Ghana office, CSIR Campus, Airport Residential Area, Accra, PMB CT 112 Cantonments, Accra, Ghana

ARTICLE INFO

Keywords:
Returns-to-scale
Tractor ownership
Inverse probability weighted generalized method of moments
Generalized propensity score
Mediation effects
Ghana

Jel classification:
O13
Q12
Q16

ABSTRACT

Agricultural transformation process around the world has often accompanied the rise in returns-to-scale (RTS). While tractor ownership is often *associated* with greater RTS in agriculture, whether the tractor ownership *actually causes* such increase in RTS has not been formally tested in the literature. We bridge this knowledge gap, using a unique survey data of tractor owning farm households in Ghana. We find that owning tractors significantly increases the RTS in maize production on the households' largest mono-cropped plot, and weakens inverse-relationship between land productivity and farm size. This is partly achieved through the rise in the "RTS in tillage production" (the amount of tillage conducted), rather than the RTS in maize production given a fixed amount of tillage produced. These sets of evidence are obtained by addressing jointly the multiple sources of endogeneity of tractor ownership, tractor values, tillage production, and other inputs used.

1. Introduction

Direct evidence is scarce in Sub-Sahara African (SSA) countries of the effects of farmer's tractor ownership on their production characteristics, including returns-to-scale (RTS), despite the general intuitions that tractors are associated with greater production scale. RTS is an important property of agricultural production technologies. RTS affects the potentials to improve productivity through optimal production scales, and also the income distributions and equality among rural households. The rise of RTS has been one of the important phenomena of agricultural transformation throughout the history (Hayami & Ruttan, 1985).

Investigating whether tractor ownership by farmers raises RTS in farm production is important because, RTS can be affected by many other potential factors, including specialization, land consolidation (Wan & Cheng, 2001), changes of crop mixes (Cramb, 2011), or biological innovations (Deininger & Byerlee, 2012). Agricultural mechanization has often been considered another factor associated with the rise of agricultural RTS (Foster & Rosenzweig, 2011; Diao et al., 2014). However, owning tractors can simply be a response to, rather than a cause of, the rise of RTS triggered by these other factors. If so, direct policies on tractor ownership have no effects on RTS, and other policies are needed to influence the RTS in the desired direction. Investigating the effects on RTS is important also because RTS is a more formal measure of the overall production scale that reflects the uses of all inputs, than simply the scale of a specific input like farm size.[1] Few studies, however, formally test whether owning tractors raises RTS, particularly among more medium-sized farms in SSA countries, which are relatively more land-abundant, and where the rise in RTS can have greater implications.

We fill this knowledge gap by showing how tractor ownership affects the RTS in agriculture, in SSA countries like Ghana, using a unique dataset of tractor-owner farm households. Aside from the data availability, Ghana offers an ideal condition to test our hypotheses; it is one of the countries where tractor ownership has recently started rising, unlike in more advanced countries where mechanization had occurred a long time ago, and where relatively more medium-sized farms are emerging (Jayne et al., 2016) unlike in Asia where smallholders still dominate.

Specifically, we show that owing tractors significantly raised the RTS in maize production on their largest mono-cropped plots, in regions of Ghana where farmer-ownership of tractors has been relatively high

* Corresponding author.
E-mail address: H.takeshima@cgiar.org (H. Takeshima).

[1] For example, Hayami & Ruttan (1985) distinguishes land-extensive farming system in USA with land-intensive farming system in Japan. Similarly, in Asia, the use of tractors is strongly associated with a greater use of traditionally land-saving inputs like chemical fertilizer among larger farms (Takeshima et al., 2017a).

https://doi.org/10.1016/j.foodpol.2018.04.001
Received 23 August 2017; Received in revised form 21 March 2018; Accepted 2 April 2018

and emerging. Furthermore, we show that such increase in RTS operates through RTS in how much tillage is done ("tillage production"),[2] rather than the change in how maize production responds to tillage.

Our contributions are mostly empirical. In particular, we offer more formal, statistical evidence that tractor ownership raises the agricultural RTS. Obtaining such evidence had been difficult due to the scarcity of sufficient samples in African countries, of tractor owners and non-owners who share relatively comparable characteristics, so that the effects of owning tractors can be identified cleanly and precisely. Furthermore, we estimate this effect by extending the impact evaluations methodologies to address complex endogeneity structures involved with these types of empirical exercises, including whether and how much to invest in tractors, and the uses of various agricultural inputs on outputs as well as tillage production. We combine inverse-probability-weighting (IPW) method, generalized methods of moments (GMM), and a mediation effects model to address these.

We contribute to the literature on agricultural mechanization in various ways. First, we provide greater insights into the household level associations between tractor ownership and key agroecological and socioeconomic factors, complementing past studies that show cross-country evidence (Otsuka et al., 2013), and qualitative evidence of tractor owners in West Africa (Houssou et al., 2017; Takeshima et al., 2015). Second, we provide more evidence that tractor ownership directly raises RTS, contributing to studies that investigate the changes in RTS over time (Hayami & Ruttan, 1985; Hayami & Kawagoe, 1989), and factors causing such changes (Takeshima, 2017a). By shedding light on the effects on RTS, we also contribute to the literature on tractor-owning mechanization service providers and smallholders (Mrema et al., 2008). Our analyses suggest that while their tractor investments may help smallholders, they can also shift comparative advantages in production to these tractor-owning farms, and direct promotion of mechanization tools suitable for smallholders may be also necessary if they cannot successfully exit the farming sector (Kahan et al., 2017). Third, we formalize the scale effects of mechanization by focusing on RTS rather than farm size. As was mentioned earlier, farm size growth alone may simply indicate the shift from land-intensive system to land-extensive system without actual changes in overall production scale. Fourth, we distinguish the effects of tractor ownership from the effects of another mode of mechanization (rental of tractors). While own machines and rented machines may be substitutable and machine hiring market may be relatively efficient in Asia and SSA (Takahashi & Otsuka, 2009; Zhang et al., 2015), few studies differentiate longer-term effects of owning tractors, such as the change in RTS. Fifth, we offer insights into how tractor ownership raises RTS. Little is understood on such mechanisms, particularly those that operate through the effects on land preparation like tillage, the operation that is most energy-demanding in rainfed agriculture (Lal, 2004) and for which tractors are primarily used at an early stage of agricultural mechanization (Binswanger, 1986). We also show that tractor ownership directly weakens the inverse-relationship of farm size and productivity, contributing to the past studies (Barrett et al., 2010; Carletto et al., 2013; Liu et al., 2016).

Lastly, we contribute to impact evaluation literature. We tie together the literature on IPW (Wooldridge, 2007) with regression adjustments and its GMM extension (Takeshima, 2017a), continuous treatment effects (Hirano & Imbens, 2004), as well as mediation effects (Huber, 2014), and demonstrate that combining their uses can provide insights into various interlinkages between technologies adoption and agricultural production characteristics.

This paper is structured as follows; Section 2 presents the conceptual framework; Section 3 describes the empirical methods; Section 4 summarizes the data, variables and descriptive statistics; Section 5 presents and discusses the empirical results, and Section 6 concludes.

2. Conceptual framework[3]

2.1. Tractor ownership and use for maize farming system in Ghana

Tractors in Ghana are obtained by individual farmers through government that occasionally distributes newly imported tractors often with subsidies, and the private market that typically trades second-hand tractors purchased through cash transactions without the involvement of formal financial sector (Diao et al., 2014).

Maize is one of the crops for which tractors are mostly used in Ghana. In Ghanaian maize farming system that is mostly rain-fed, tractors are primarily used for land preparation, particularly tilling and harrowing of hard soils at the beginning of the production season. The tilling practice in maize system is new, and generally emerging in more densely-populated areas, consistent with Boserup (1965) and Diao et al. (2014). Maize plots are tilled once or multiple times, depending on the soil conditions. Second most common use of tractor is carting of farm products and inputs, laborers (Chapoto et al., 2014). Some tractors are used for shelling maize (Diao et al., 2014).

Tractor values in Ghana are closely correlated with engine horsepower. Greater tractor values therefore generally indicate greater ability to till soils deeper, and also till greater area per unit of time. The returns from greater horsepower may be particularly high for working soils with greater bulk density, or clayey soils. However, the merits of greater horsepower for transportation may generally be limited, particularly if it reduces its mobility.

2.2. Tractor ownership and potential increase in RTS

Tractor ownership can raise RTS through various mechanisms. RTS may rise due to increased productivity (or reduced loss of productivity) at the intensive margins of various inputs or services. Farm mechanization mitigates the decline of marginal productivity at intensive margins, if, unlike manual labor, the continuous work does not lower the productivity through fatigue. Switching from rented tractors to owned tractors may further raise the RTS. For example, the supply of rented tractors may be price inelastic due to the accessibility constraints, so that the marginal productivity of expenditures on renting tractors declines. This is less so for owned tractors. Opportunity costs for them may not rise quickly at the intensive margins because the limited mobility of tractors and seasonality of demand still limit the spatial and temporal scope of tractor uses outside their farms (Takeshima et al., 2015). As the farm expands beyond the medium-scale, tractors become exclusively used on farms owned by the tractor owners, reducing their uses for hiring out (Houssou et al., 2015).

With constrained accessibility to custom hiring service, owning tractors may also allow more efficient preparation of larger plots, because of reduced transactions costs associated with finding more custom-hiring service providers, and negotiating the fees, which can be spent for more productive activities. RTS may increase either through the efficiency of tilling greater areas, or the returns to each unit of tilled area. Owning larger tractors (proxied by greater values) may further raise RTS because of greater mechanical power that is substituted for labor (tractor operators).

The ownership of tractor may not only raise the RTS in a relative term. It may also achieve increasing RTS as opposed to constant RTS, if the marginal productivity remains high as described above, while the reduction in average production costs is substantial because of large fixed effects associated with tractor investment.

[2] We use the term "tillage production" to indicate the frequency of tillage multiplied by the areas tilled. Tillage production is one of the important intermediate outputs, which affect the final maize outputs.

[3] More technical expositions of conceptual framework are provided in Takeshima et al. (2017b).