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Innovation inputs and efficiency: manufacturing firms in Sub-Saharan Africa

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Abstract

Purpose – Countries in Africa have a common goal policy of industrialisation that is expected to be driven by investing in innovation that yields efficiency. The purpose of this paper is to investigate the technical efficiency effects arising from innovation inputs including internal R&D, human capital development (HCD), and foreign technology adoption in manufacturing firms in Africa.
Design/methodology/approach – This study uses cross-sectional firm-level survey data from the 2013 World Bank Enterprise Survey and the linked 2013 Innovation Follow-up Survey. A heteroscedastic half-normal stochastic frontier is used for analysing the technical efficiency effects of innovation inputs of 418 firms.
Findings – This study reveals that internal R&D, and foreign technology have negative effects on technical efficiency. Notwithstanding, the combination of foreign technology and internal R&D, and foreign technology and HCD reinforce each other's effects on technical efficiency.
Practical implications – This study provides evidence that whereas individual innovation inputs may not yield positive efficiency outcomes, the combination of absorptive capacity enhancing inputs comprising internal R&D and HCD with foreign technology is vital for enhancing technical efficiency in manufacturing firms in Africa. This study offers important lessons for managers in manufacturing firms in Africa.
Originality/value – This study is virtually the first to investigate the relationship between innovation inputs and efficiency in Africa. This study demonstrates that investing in foreign technology in isolation from absorptive capacity enhancing innovation inputs diminishes efficiency. HCD and internal R&D are imperative for building absorptive capacity that enhances efficiency outcomes arising from foreign technology.

Keywords Africa, Manufacturing, Technical efficiency, R&D, Human capital development, Foreign technology adoption

Paper type Research paper

1. Introduction

Developing countries have become increasingly aware of the important role that innovation and efficiency play in driving economic growth and development. Innovation has been described as a "creative destruction" process that underlies economic development (Schumpeter, 1942).

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The innovation process at the firm-level entails the transformation of internal organisational innovation inputs including internal R&D, and human capital development (HCD) into product and process innovations. Furthermore, the innovation process also encompasses external innovation inputs involving the adoption of foreign technology. Internal R&D is defined as creative work undertaken for increasing the development of innovative products and processes. HCD on the other hand relates to formal training of workers that is associated with increased absorptive capacity that is crucial for innovation and efficiency (Cohen and Levinthal, 1990; Vandenbussche *et al.*, 2006). The adoption and imitation of foreign technology entails the use of technology licensed from foreign-owned companies for enhanced productivity and efficiency. Imitation is associated with the extent to which firms invest in imitative research activities when adopting foreign technology (Cameron *et al.*, 2005). Thus, firms may invest in internal R&D, HCD, and/or adopt foreign technology (Cohen and Levinthal, 1990) as innovation inputs aimed at increasing productivity and efficiency in the transformation of factors of production. Technical efficiency is a fundamental measure of economic efficiency that refers to the maximum possible output that can be obtained from a given a set of inputs (Aigner *et al.*, 1977). Achieving technical efficiency has been thought to produce the highest gains for firms. This is because the fundamental problem of scarcity of resources implies that firms must employ new and more efficient methods of production. Hence, scarcity of resources attaches importance to efficiency since resource constrained firms aim to produce maximal output (Luptáčik, 2009) subject to scarce resources.

The manufacturing sector in developing countries is a significant engine of growth and technological catch up. This sector is viewed as a source of modernisation, skilled job creation and positive spillover effects (Tybout, 2000). Efficiency in the manufacturing sector in developing countries is critical for industrialisation, yet, inefficiency is a distinctive feature of the manufacturing sector in developing countries in Sub-Saharan Africa (SSA) (Sleuwaegen and Goedhuys, 2003). Other distinctive features of the operational environment of manufacturing firms in developing countries in SSA include limited access to specialised manufactured inputs, lack of skilled human capital, poor infrastructure, macroeconomic volatility, poor governance (Tybout, 2000), and lack of formal R&D (Biggs, 1995).

In as much as persistent disparities in various firm-level characteristics result in relative differences in efficiency (Korres, 2012), a review of previous literature indicates that there are virtually no empirical studies examining how innovation inputs impact technical efficiency in developing countries and more so in SSA. Most studies focus on firm size, age and efficiency (Cheruiyot, 2017; Diaz and Sánchez, 2008; Lundvall and Battese, 2000; Niringiye *et al.*, 2010; Sánchez-Pérez and Díaz-Mayans, 2013). Thus, while it is widely known that productivity is driven by technical efficiency, the extent to which innovation inputs influence efficiency in firms remains unclear (Fu *et al.*, 2011). Additionally, one distinctive feature of developing countries in SSA relates to the large population that mainly consists of unskilled or semi-skilled human capital (Biggs, 1995; Tybout, 2000). Furthermore, since SSA is characterised as a technology follower, HCD is likely to play a critical role in contributing to the absorption of foreign technology. Yet, there is a dearth of literature examining how absorptive capacity arising from internal R&D and HCD moderates the effect of foreign technology adoption on technical efficiency at the firm-level in the context of SSA. Most empirical studies examine this relationship at the macro-level in the context of total factor productivity (Benhabib and Spiegel, 1994; Eaton *et al.*, 1998; Griffith *et al.*, 2003, 2004; Madsen *et al.*, 2010; Tang and Zhang, 2016). Hence, investigating the sources of technical efficiency in manufacturing firms in developing countries presents a pertinent issue that warrants study.

This study posits that manufacturing firms in developing countries are likely to realise efficiency gains by conducting internal R&D, engaging workers in HCD programs, and by using foreign technology for production. Nevertheless, successful adoption of foreign technology is also contingent on the degree of absorptive capacity which is directly associated with internal R&D and HCD. Thus, this study asserts that internal R&D in combination with the foreign technology adoption significantly enhances efficiency in the context of manufacturing firms in SSA. Similarly, this study argues that efficiency gains are likely to be realised when foreign technology adoption is coupled with HCD. Hence, this study addresses the following research question:

RQ1. How do innovation inputs affect technical efficiency in manufacturing firms in SSA?

The main motivation of this research arises from the fact that while extant literature underscores the importance of innovation and efficiency for firm growth, no deliberate efforts have been made in linking innovation and efficiency. Essentially, innovation and efficiency have typically been studied in isolation from each other. There is scant literature on innovation inputs and their effects on technical efficiency at the firm-level in SSA, which can be attributed to the unavailability of firm-level data on innovation. This study therefore fills this knowledge gap by shedding light on the implications of the link between innovation inputs and efficiency in the context of developing countries in SSA.

Hence, this study makes several contributions. First, using new firm-level data from the 2013 World Bank Enterprise Survey (WBES) and the linked 2013 Innovation Follow-up Study (IFS), this study sheds light on the efficiency effects of internal R&D, HCD, and foreign technology adoption in manufacturing firms from six countries in SSA including Ghana, DRC, Kenya, Tanzania, Uganda, and Zambia. Essentially, these countries lie farther behind the technological frontier and efficiency gains are likely to be realised from investing in the aforementioned innovation inputs. Second, taking into cognisance that foreign direct investment is a primary source of foreign technology, this study also examines the efficiency effects of foreign ownership arising from foreign direct investment. Third, this study examines whether the combination foreign technology with internal R&D, and HCD, respectively, significantly enhances technical efficiency. There are virtually no studies investigating efficiency effects in the context of absorptive capacity arising from internal R&D and HCD at the firm-level in SSA. Yet, it is inherently difficult for firms to acquire tacit knowledge without actively engaging in internal R&D, which enhances the ability to understand and easily assimilate external knowledge associated with foreign technology. In addition, HCD is critical for successful absorption of advanced technologies embodied in foreign technology. This raises the question of what absorptive capacity measures matter for promoting technical efficiency in manufacturing firms in developing countries in SSA. This study therefore provides important insights into the relationship between innovation inputs and technical efficiency in the context of manufacturing firms in SSA. An empirical investigation of the efficiency effects of innovation inputs is particularly relevant given that industrialisation is a common policy goal for developing countries in SSA.

The remainder of this paper is structured as follows. Section 2 presents the literature review and hypotheses. Section 3 elucidates the methodology of the study and discusses the sources and types of data including the how the analysis of the data is conducted. Section 4 presents the results of the analysis and subsequent robustness checks. The paper concludes with Section 5 which offers the discussion that includes managerial implications, avenues for future research, and the conclusion.

2. Literature review and hypotheses

A technically efficient firm is one in which an increase in an output requires an increase in at least one input or a reduction in at least one other output. Moreover, a decrease in an input has to be accompanied by a reduction in at least one other output or an increase in one other input (Koopmans, 1951; Porcelli, 2009). Thus, the notion of technical efficiency relates to the maximisation of output subject to a given set of factors of production. Given the technology used, inefficiency is the difference between the observed output and the maximum obtainable output. The production possibilities frontier (PPF) provides microeconomic foundations of technical efficiency. The PPF defines the maximum potential output that can be achieved by a firm for a given set of inputs and technology. Inefficiency gives rise to deviations from the maximum potential output. Determining efficiency differences between firms entails estimating the production frontier where efficient firms are located. The inefficiency scores of the remaining firms are then derived by obtaining their deviation from the frontier (Chen *et al.*, 2015; Gumbau-Albert and Maudos, 2002).

Efficiency in productivity had been largely ignored because of the inherent difficulties encountered in determining producers' potential and the producers' achievement of that potential. While it is widely known that efficiency measures are essentially success indicators by which producers are evaluated, economic theory had for a long time failed to provide a theoretical framework shedding light on factors influencing efficiency in production (Fried *et al.*, 2008). Nevertheless, several authors examine determinants of efficiency using firm-specific characteristics, external factors, ownership, and dynamic disturbances that may arise from the degree of a firm's technological innovation (Caves, 1992; Cheruiyot, 2017; Vu, 2016).

Internal R&D, HCD, and the adoption of foreign technology may affect technical efficiency in several ways. First, conducting internal R&D may increase the efficiency of existing operations (Cohen and Levinthal, 1989; Un and Asakawa, 2015). This may be achieved by means of cost reduction or through minimising wastage of production inputs. Second, internal R&D increases innovation activity that may yield new products and services resulting in increased competitive advantage (Coccia, 2017). However, sustaining competitive advantage involves efforts to produce high levels of output from minimal inputs. Third, human capital theory indicates that investing in HCD engenders improvements in the skills and quality of the existing human capital base (Hong *et al.*, 2016; Lall *et al.*, 2016). Thus, HCD enhances organisational competencies that can be leveraged as a source of competitive advantage and efficiency (Danquah and Ouattara, 2014; Marimuthu *et al.*, 2009; Wang and Wong, 2012). Fourth, the adoption of foreign technology from developed countries may increase efficiency if imported equipment is suited to the socio-economic environment of the adopting developing countries (Fu *et al.*, 2011). Notwithstanding, several arguments have been advanced in favour of combining foreign technology adoption with internal R&D and HCD over the use of a single innovative input.

On the one hand, firm-level innovation by means of investing in internal R&D is a risky and costly path-dependent process in comparison to the adoption of foreign technology (Fu *et al.*, 2011). Hence, firms in developing countries have a higher likelihood of adopting foreign technology. On the other hand, the adoption of foreign technology is dependent on the firm's capacity to absorb new knowledge (Cohen and Levinthal, 1989), which is conditioned on internal R&D and HCD (Lewandowska, 2015; Tang and Zhang, 2016). In addition, foreign technology may not be suited to the socio-economic conditions of developing countries (Acemoglu, 2002; Basu and Weil, 1998) since they may have a limited capacity for making optimal use of the technology embedded in foreign technologies. Thus, the solution for enhancing efficiency may lie in combining foreign technology adoption with internal R&D for leveraging innovation capabilities (Fu *et al.*, 2011). Griffith *et al.* (2004) provide evidence supporting the idea that interacting foreign technology adoption with internal R&D yields efficiency gains. The authors find that internal R&D raises the rate of technology transfer from technologically advanced countries to non-frontier countries.

Furthermore, HCD is critical in building absorptive capacity (Lewandowska, 2015), which enhances technological expertise that is critical for adopting foreign technology and identifying opportunities for promoting efficiency (Lecerf, 2012). Africa is endowed with an abundant labour force that chiefly consists of unskilled and semi-skilled workers (Biggs, 1995; Tybout, 2000). Hence, HCD initiatives involving formal training programs significantly contribute to adapting foreign technology to the local conditions. HCD is therefore imperative for efficient and successful absorption of foreign technology (Blundell *et al.*, 1999; Madsen *et al.*, 2010). Thus, foreign technology adoption in combination with HCD is likely to yield efficiency gains in manufacturing firms in SSA. In spite of the highlighted arguments, the topic of efficiency effects of innovation inputs has remained under researched in the context of SSA. Hence, there is very sparse literature examining how internal organisational innovation inputs such as internal R&D and HCD, and external innovation inputs involving the adoption of foreign technology affect technical efficiency. While it is expected that internal R&D, HCD, and the adoption of foreign technology have significant effects on technical efficiency, this study further hypothesises that efficiency effects of foreign technology adoption are conditioned on the absorptive capacity building nature of internal R&D and HCD. This area of study has received sparse attention in the context of manufacturing firms in developing countries in SSA. Hence, the relationship between innovation inputs and technical efficiency remains unclear. This study therefore seeks to fill this knowledge gap by testing several hypotheses which are discussed in more detail in the succeeding sections.

2.1 Internal R&D and technical efficiency

Internal R&D is a key innovation input that is fundamental in explaining technical efficiency arising from the development of new technologies at the firm-level (Baumann and Kritikos, 2016; Bonanno, 2016; Guan and Yam, 2015). Nevertheless, internal R&D has been found to have ambiguous effects on technical efficiency. On one hand, firms investing in R&D have been found to be more productive and efficient (Baumann and Kritikos, 2016; Bonanno, 2016; Kim, 2003; Kumbhakar *et al.*, 2012; Mitra and Jha, 2016; Sheu and Yang, 2005). Torii (1992) suggests that R&D expenditure is positively associated with efficiency due to the increased capacity for introducing new products and production processes. Therefore, internal R&D fosters efficiency because it gives rise to indigenous technology that is suited to the socio-economic and technological conditions of domestic firms (Li, 2011). Contrastingly, various empirical studies report a negative relation between internal R&D and technical efficiency. Gumbau-Albert and Maudos (2002) in their study examining the determinants of efficiency in the manufacturing industry in Spain find a negative relation between R&D expenditure and efficiency. The authors cite two reasons for this anomalous finding. First, they argue that R&D expenditure may have dynamic effects. The effect of current R&D expenditure on innovation may only be observed in a future time period. Hence, the current period is likely to be characterised by inefficiency. Second, there is a possibility that some firms engage in excessive R&D expenditure relative to their competitors, which results in innovation, but gives rise to inefficiency in these firms. Furthermore, Torii (1992) argues that rapid technological innovation driven by R&D in a firm results in relative inefficiency in non-innovating firms. Internal R&D is therefore likely to have mixed effects on technical efficiency. Thus, the following hypothesis is proposed:

H1. Internal R&D has a significant effect on technical efficiency.

2.2 HCD and technical efficiency

Africa, being the second-largest and one of the most populous continents in the world boasts of a relatively large labour force. Yet, Africa's quantitatively large labour force has been found to be lacking in terms of skills and quality (Tybout, 2000). Inadequate skills and a low quality of the labour force contribute to inefficiency in manufacturing firms in SSA. Hence, HCD encompassing knowledge and qualifications acquired through formal training is imperative for improving skills and quality of the labour force (Lall *et al.*, 2016). Formal training is a fundamental element of HCD (Altarawneh, 2009) that is likely to yield productive and efficient workers as they are better able to perform tasks and embrace new production techniques (Arshad and Ab Malik, 2015; Blundell *et al.*, 1999; Bronzini and Piselli, 2009; Dimelis and Papaioannou, 2014; Hong *et al.*, 2016; Lall *et al.*, 2016; Madsen *et al.*, 2010). Various authors find that HCD has a positive and statistically significant effect on technical efficiency in developing countries in Africa (Danquah and Ouattara, 2014; Gokcekus *et al.*, 2001; Oyelaran-Oyeyinka and Lal, 2006). Similarly, Biggs (1995) provides empirical evidence that formal training fosters technical efficiency in manufacturing firms in several countries in SSA including Ghana, Kenya, and Zimbabwe. Hence, the hypothesis is formulated as follows:

H2. HCD has a positive effect on technical efficiency.

2.3 Foreign technology and technical efficiency

The adoption of foreign technology may be considered as an alternative to internal R&D. Firms may opt to adopt foreign technology because of the prohibitive costs involved in R&D investment (König *et al.*, 2016). Moreover, firms lying farther away from the technological frontier face vast opportunities for adopting foreign technology. Hence, imitation and adoption of foreign technology are vital for technological catch up (Crespi and Zuniga, 2012) in the context of developing countries (Fu *et al.*, 2011; Lall *et al.*, 2016). Two key sources of foreign technology that significantly impact technical efficiency include foreign technology adoption which involves the use of technology licensed from foreign-owned companies, and foreign ownership arising from foreign direct investment. There is a likelihood that foreign technology yields efficiency gains. Yet, adoption of foreign technology that is not suited to socio-economic and technological conditions in developing countries may give rise to inefficiency (Basu and Weil, 1998). Imported technologies are biased towards making optimal use of factors of production in the context of the country in which they are produced, therefore, applying such technologies in a country with a significantly different factor endowment is likely to result in suboptimal efficiency gains (Acemoglu, 2002; Lall *et al.*, 2016). In addition, developing countries are characterised by an abundance of semi-skilled and unskilled labour. This poses a major obstacle to the learning and application of the technology embedded in foreign technologies (Fu *et al.*, 2011). There is therefore a high probability of foreign technology adoption resulting in inefficiency in the context of manufacturing firms in SSA.

With regards to foreign ownership, this study argues that foreign-owned firms have a higher likelihood of acquiring inputs, equipment, and machinery from the host country. Typically, technology is embodied in the new imported inputs, equipment, and machinery (Lall *et al.*, 2016; Wagner, 2012). In contrast to foreign technology adoption, foreign ownership is more likely to have positive efficiency effects (see Ulku and Pamukcu, 2015) in the context of manufacturing firms in SSA. There are two main reasons for this argument. First, foreign ownership is often a source of human capital. This is particularly true in instances where new management and production practices are adopted. Hence, firms are likely to adapt imported technology with relative ease. Second, foreign ownership may also afford host countries with labour training opportunities (Borensztein *et al.*, 1998; Sánchez-Sellero *et al.*, 2014; Ubeda and Pérez-Hernández, 2017; Vu, 2016). Hence, it is likely that foreign technology arising from foreign ownership results in efficiency gains for manufacturing firms in developing countries (Mazaheri and Mazumdar, 2005). Given the context of this study, this study argues that the adoption of foreign technology has ambiguous efficiency effects. Nevertheless, foreign ownership is more likely to have positive effect on efficiency. Thus, the study hypothesises that:

H3. Foreign technology adoption has a significant effect on technical efficiency.

H4. Foreign ownership has a positive effect on technical efficiency.

2.4 Absorptive capacity and technical efficiency

An important determinant of a country's success in adopting foreign technology is measured by the degree of "imitative" or "adaptive" research activities. This is because adaptation usually precedes adoption of technology (Cameron *et al.*, 2005). Previous empirical studies also suggest that internal R&D and foreign technology are complementary innovation inputs. This is because there is a high likelihood of firms relying on their research capacity for modifying and adopting foreign technologies to meet their specific needs (Chang and Robin, 2006). This idea led to the distinction between "creative" and "absorptive" R&D with the former relating to original inventions and the latter being oriented towards adoption of foreign technology. Thus, successful adoption of foreign technology is conditioned on the firm's absorptive capacity. Absorptive capacity relates to the ability of identifying, assimilating and exploiting knowledge from the external environment (Cohen and Levinthal, 1989). The degree of absorptive capacity depends on human capital and internal R&D, which are crucial for creating new knowledge and promoting learning (Cozza and Zanfei, 2016; Crespi and Zuniga, 2012; Griffith *et al.*, 2004; Hong *et al.*, 2016; Kim, 2015; Kontolaimou *et al.*, 2016; Tang and Zhang, 2016; Wang and Wong, 2012). Successful adoption of foreign technology is therefore contingent on indigenous innovation efforts comprising internal R&D (Fu *et al.*, 2011) and HCD (Bronzini and Piselli, 2009; Lewandowska, 2015). Foreign technology and internal R&D efforts are complementary and relying on only one innovation input results in suboptimal efficiency gains in developing countries (Fu and Gong, 2011; Rifkin, 1975). Therefore, foreign technology enhances innovation-oriented efficiency only when coupled with "absorptive" internal R&D (Li, 2011). Furthermore, it has been argued that firms may import technology from more advanced countries in Africa so that less technical effort is required for adoption and imitation (Biggs, 1995) as conditioned on similarities in the socio-economic and technological environment. This implies that semi-skilled and unskilled labour that is a distinctive feature of human capital in SSA may be sufficient for exploiting foreign technology. Nevertheless, firms in SSA are more likely to import technology from relatively advanced countries. Hence, efficiency gains can only be realised when foreign technology is coupled with HCD. Essentially, HCD involves a firm's human resource department facilitating training of employees for building absorptive capacity. Lastly, relatively few firms in SSA engage in formal R&D activities and consequently exhibit sparse innovation-oriented R&D (Biggs, 1995). Hence, internal R&D efforts are likely to be "absorptive" in nature. Thus, this study contends that efficiency gains originating from successful adoption of foreign technology are conditioned on internal R&D, and HCD, respectively. Hence, this study proposes the following hypotheses:

H5. Foreign technology adoption in combination with internal R&D reinforce each other's effects on technical efficiency.

H6. Foreign technology adoption in combination with HCD reinforce each other's effects on technical efficiency.

Building on the literature review and hypotheses, we propose the hypothetical framework shown in Figure 1. This framework summarises the relationships described in the six hypotheses including the direct effects and interaction effects of innovation inputs on technical efficiency.

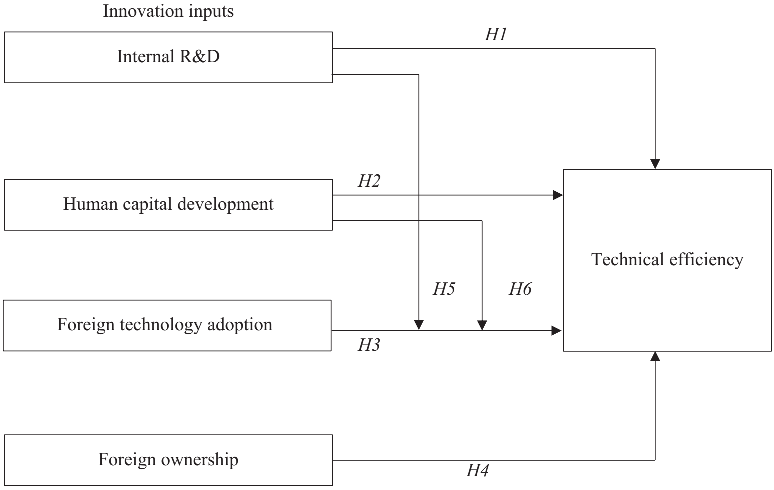

Figure 1.
Hypothetical framework

3. Methodology

3.1 Data

Cross-sectional firm-level survey data for manufacturing firms in Ghana, DRC, Kenya, Tanzania, Uganda, and Zambia from the 2013 WBES and the linked 2013 IFS is used for testing the hypothetical framework displayed in Figure 1. The WBES reports on individual firm characteristics, infrastructure and services, sales and supplies, competition, finance, performance and the business environment of an economy among other indicators. The IFS reports on several types of firm-level innovation including product innovation, process innovation, organisational innovation, and marketing innovation. The stratified random sampling methodology is used in for selecting a representative sample of the economy's private sector. The strata comprise firm size, business sector, and the geographical location of a firm. The survey respondents are typically business owners and top manager. However, in some instances, survey respondents invite human resource managers and company accountants to answer questions relating to labour and sales, respectively (www.enterprisesurveys.org). The WBES and IFS provide firm-level information for the years 2010 through 2012. The two data sets were then merged using unique firm identifiers to generate a single data set for analysis. All observations with missing values on the variables of interest including output and production inputs were deleted to obtain a data set containing 418 manufacturing firms that have complete data.

3.2 Dependent variable

The production frontier is estimated using the standard variables comprising output, capital and labour. Annual sales is used a measure of output. The WBES provides information on "last complete fiscal year's total sales" which the study uses as a measure of output. Hence, output relates to total sales in 2012. Capital inputs have been found to account for a larger share of output growth. Hence, capital is a vital input in the production process. The WBES reports on fixed assets, which the study uses as a measure of capital. This variable is measured as the 2012 net book value (NBV) of fixed assets which was calculated by adding the NBV of machinery, vehicles and equipment to the NBV of land and buildings. The WBES reports assets value relating to the "last complete fiscal year". Penn World Tables purchasing power parity (PPP) exchange rates were used for deflating output and capital measures in order to determine relative values of currencies for Ghana, DRC, Kenya, Tanzania, Uganda, and Zambia. The WBES also provides information on the number of "permanent, full-time workers at the end of the last complete fiscal year" (i.e. 2012) which the study uses to measure labour.

3.3 Independent variables

Internal R&D. The IFS reports on whether firms conducted internal R&D over the survey period (i.e. 2010-2012), which the study measures as a dummy variable taking a value of "1" if a firm reported conducting internal R&D and "0" if otherwise.

HCD. This variable relates to the development of human capital. The WBES reports on whether a firm provided its full-time employees with formal training. HCD is a dummy variable taking a value of "1" where a firm's reports that it provided formal training to its workers in the last complete fiscal year (i.e. 2012) and "0" if otherwise.

Foreign technology adoption. Use of foreign technology is reported in the WBES which provides information on whether the firm "at present" uses technology licensed from a foreign-owned company. This is a dummy variable taking a value of "1" if the firm reported using technology licensed from a foreign-owned company and "0" if otherwise[1].

Foreign ownership. Foreign ownership, an important form of foreign direct investment is reported in the WBES as the percentage of ownership by private foreign individuals, companies or organisations. A dummy variable is used for measuring foreign ownership. This dummy variable takes a value of "1" if a firm reports at least 10 per cent foreign ownership and "0" if otherwise.

3.4 Control variables

Age. This is a firm-specific characteristic with ambiguous effects on efficiency. A positive relation may occur due to learning-by-doing arising from cumulative experience in production. Notwithstanding, a negative relation may arise from use of old capital equipment and inefficient production practices (Deraniyagala, 2001). The WBES provides information on age which is measured as the difference between the year of the survey and the year the firm began its operations.

Size. The effect of firm size on technical efficiency is ambiguous (Niringiye *et al.*, 2010). The WBES reports on the "number of full-time employees in the last fiscal year". Size is a dummy variable taking a value of "1" where a firm has more than 20 employees and "0" if otherwise. Firms with less than 20 employees are categorised as small and micro enterprises in the WBES. Firms with more than 20 employees fall in a continuum of medium to large-sized firms.

Export status. Exporting firms are more efficient than non-exporting firms (Bigsten and Gebreeyesus, 2009). The WBES reports the percentage of sales accounting for direct or indirect exports. This study measures export status using a dummy variable taking a value of "1" if a firm is a direct or indirect exporter and "0" if otherwise.

Imports. Inputs of foreign origin are also likely to be important for efficiency in the context of developing countries in Africa. Foreign inputs of high quality or possessing embodied technology may enhance efficiency (Wagner, 2012). The WBES reports on the percentage of material inputs or supplies of foreign origin which is used as a measure for imports[2].

External financing. External financing pertains to working capital that is obtained from external sources including banks, non-bank financial institutions, and supplier credit. External financing boosts efficiency by facilitating a firm's day-to-day operations (Nickell and Nicolitsas, 1999). The WBES reports on the proportion of the firm's working capital financed from external sources. External financing is measured using a dummy variable taking a value of "1" if working capital from external sources exceeds 50 per cent and "0" if otherwise.

Access to credit. Access to credit plays a vital role in enhancing efficiency since firms are better placed to invest in key innovation inputs such as internal R&D, HCD, and foreign technology that yield efficiency improvements (Nickell and Nicolitsas, 1999). Access to credit is measured as a dummy variable taking a value of "1" if a firm reports having a line of credit or loan from a financial institution and "0" if otherwise as reported in the WBES.

Educational attainment. Highly educated workers are essentially more productive and efficient as they are better able to perform tasks and embrace new production techniques (Danquah and Ouattara, 2014). Educational attainment of workers is measured as the percentage of full-time permanent employees with secondary school education as reported in the WBES.

Managerial experience. Firms with experienced managers have been found to be more technically efficient (Mazaheri and Mazumdar, 2005). The WBES reports managerial experience as the number of years that a top manager or business owner has worked in a given sector. Managerial experience is a dummy variable taking a value of "1" where a business manager has at least 15 years of experience in a sector and "0" if otherwise.

Formal status. Informal firms are generally less efficient than formally registered firms (La Porta and Shleifer, 2014). The WBES asks respondents whether the firm was formally registered when it began operations. Formal registration of a firm at the commencement of operations indicates compliance with rules and regulations, which is likely to enhance efficiency. Formal status is a dummy variable taking a value of "1" if the firm was formally registered at the start of its operations, and "0" if otherwise.

Capacity utilisation. The degree of capacity utilisation is positively associated with efficiency (Mukwate and Muniu, 2012). Manufacturing firms in SSA typically utilise about 50 per cent of their capacity (Mazaheri and Mazumdar, 2005). The WBES reports on the production of a firm in the last complete fiscal year as proportion of the maximal possible output if all the available resources were used. This variable is measured as a dummy variable that takes a value of "1" where capacity utilisation is at least 50 per cent and "0" if otherwise.

ICT infrastructure. The use of ICT can be regarded as a measure of infrastructural development that is expected to have positive efficiency effects. The IFS seeks information on whether a firm "currently" has an internet connection. Firms may use the internet for communication, online purchasing, online sales and marketing, inventory management, and for researching and developing ideas for new products or processes. Apart from the use of internet indicating a high level of infrastructural development that is positively associated with efficiency, the use the internet for normal business operations enhances efficiency in a firm due to associated cost reductions and improved product quality (Mouelhi, 2009). ICT infrastructure is a dummy variable taking a value of "1" where a firm reports having an internet connection and "0" if otherwise.

Informal competition. More competitive markets are associated with higher levels of efficiency (Nickell, 1996). Notwithstanding, unregistered or informal competitors may drive firms to engage in inefficient operational practices due to low pricing (see La Porta and Shleifer, 2014). The WBES reports on whether firms face competition from unregistered or informal firms. Informal competition is a dummy variable taking a value of "1" where a firm does not face competition from unregistered or informal firms and "0" if otherwise.

Industry dummies. Industry dummies are used as explanatory variables for the variance in the idiosyncratic error component of the inefficiency effects model to account for differences between industries (Belotti *et al.*, 2012). This study controls for industry differences by using the International Standard Industry Classification (Rev. 3) to categorise firms as high-technology, medium-technology, and low-technology (reference category). This information is reported in the WBES.

Country dummies. Country dummies are used as explanatory variables for the variance in the idiosyncratic error component of the inefficiency effects model to control for differences between Ghana, DRC, Kenya, Tanzania, Uganda, and Zambia. Kenya is the reference category. Country dummies are essential for capturing variation in the external environment and market conditions to account for country specific effects.

3.5 Analysis

There are two competing methods of measuring efficiency including the stochastic frontier analysis (SFA), a parametric approach (Aigner *et al.*, 1977; Meeusen and van Den Broeck, 1977) and the non-parametric data envelope analysis (DEA) approach (Charnes *et al.*, 1978). In an environment characterised by "noise", the SFA provides better efficiency estimates in comparison to DEA since the SFA allows for random disturbances (Kumbhakar and Lovell, 2003). The SFA therefore has the advantages of testing hypothesis due to its parametric approach, and distinguishing between inefficiency and "noise" thereby coping with measurement error. Furthermore, it also allows for the use of classical estimation methods such as the method of maximum likelihood (MML) and likelihood ratio (LR) tests.

The SFA is based on estimating the frontier production function arising from the microeconomic premise that firms produce maximum output subject to a set of inputs (Aigner *et al.*, 1977; Meeusen and van Den Broeck, 1977). The SFA has three components including the deterministic production function, the idiosyncratic (noise) error and the inefficiency error. Applying a one-step approach cross-sectional stochastic frontier and an inefficiency effects model are estimated simultaneously by the MML, with inefficiency effects being explained by the independent variable and control variables (Belotti *et al.*, 2012). The one-step approach circumvents the inconsistency arising from using a two-step approach where the stochastic frontier is first estimated and inefficiency scores are obtained without taking into account the environmental factors under the assumption of independently and identically distributed inefficiency effects. Notwithstanding, inefficiency effects are then assumed to be a function of firm-specific variables in the second step, which is inconsistent with the assumption that inefficiency effects are identically distributed. Previous studies adopting the one-step model include Diaz and Sánchez (2008) whose study focusses on determinants of technical inefficiency in manufacturing firms in Spain, Kumbhakar *et al.* (2012) with their study examining the impact of corporate R&D activities on labour productivity in Europe's top R&D investor firms and Sánchez-Pérez and Díaz-Mayans (2013) who investigate efficiency in large innovative firms in Spain. Following Belotti *et al.* (2012)the one-step model takes on a function relating the maximum obtainable output to a set of inputs such that for a given firm i:

$$y_i = f(x_i, \beta)\exp(v_i)\exp(-u_i) \quad i = 1,\ 2, \ldots, n. \tag{1}$$

where y_i is the output for observation i, $f(x_i, \beta)$ is the deterministic component of the production function in which x_i is the input vector for observation i and β is a vector of parameters, the first error component $\exp(v_i)$ is the stochastic component of the production function accounting for the random disturbances in the production processes and is assumed to have a symmetric mean and zero mean $v_i \sim N(0,\ \sigma_v^2)$, and the second error component u_i represents technical inefficiency and is assumed to be identically and independently distributed of v_i to satisfy the restriction of $u_i \geqslant 0$ which follows a half-normal distribution $v_i \sim N^+(0,\ \sigma_u^2)$ (Aigner *et al.*, 1977) or an exponential distribution $u_i \sim \varepsilon(\sigma_u)$ (Meeusen and van Den Broeck, 1977). Equation (1) represents the general form of a stochastic frontier production function that allows for the impact of shocks on technical inefficiency caused by variation in inputs to be isolated from the effect of environmental variables. The standard assumptions made include having a random sample, hence independence over i; that x_i, v_i, and u_i are mutually independent; and that u_i follows a half-normal distribution (Aigner *et al.*, 1977). The MML is appropriate for estimating the model due to the distributional assumptions required for the inefficiency term, which makes it possible to derive a likelihood function that is maximised with respect to all parameters (β, σ_v^2 and σ_u^2) to obtain consistent estimates of β (Hadri, 1999).

The implicit assumption is that the leading firm is itself the frontier and the benchmark for the rest of the firms. Some firms may produce less than the frontier output due to inefficiency. Following Kumbhakar *et al.* (2012), this study considers that if the ratio between the maximum and actual output is $\exp(-u_i)$, the inefficiency measure becomes:

$$e_i^{sf} = \exp(-u_i) = \frac{y_i}{f(x_i,\ \beta)\exp(v_i)} \quad i = 1,\ 2, \ldots, n. \tag{2}$$

where $e_i^{sf} \in (0, 1]$ and unity values indicate fully efficient firms. A log-linear production function is used for estimating the frontier so that Equation (1) becomes:

$$\ln y_i = \ln f(x_i, \beta) + v_i - u_i \quad i = 1,\ 2,\ \ldots,\ n. \tag{3}$$

where $u_i = \log 1/e_i^f$ and $f(x_i, \beta)$ can assume a Cobb-Douglas or transcendental logarithmic (translog) functional form. The Cobb Douglas production function and translog production function are shown in Equations (4) and (5), respectively:

$$\ln (Y)_i = \beta_0 + \beta_1 \ln (K)_i + \beta_2 \ln (L)_i + v_i - u_i \tag{4}$$

$$\ln (Y)_i = \beta_0 + \beta_1 \ln (K)_i + \beta_2 \ln (L)_i + \beta_3 \ln (K)_i^2 + \beta_4 \ln (L)_i^2 + \beta_5 \ln (K)_i \ln (L)_i + v_i - u_i \tag{5}$$

where Y_i represents PPP-deflated sales revenue for firm i, K_i represents PPP-deflated NBV of fixed assets for firm$i$, L_i is the number of full-time workers for firm i while v_i and u_i are random error terms representing the idiosyncratic error component and inefficiency effects component for firm i. The Cobb-Douglas model represents the restricted model while the translog model represents the unrestricted model consisting of squares and cross-products of the inputs.

The adequacy of the Cobb-Douglas functional form relative to the less restrictive translog functional form is tested using the generalised LR test. In the selection of the functional form, the null hypothesis is that the Cobb-Douglas provides an adequate representation of the data. The null hypothesis is strongly rejected ($\rho < 0.001$). Hence, the model that is estimated takes the form of a translog production function shown in Equation (5). This is a more flexible functional form that circumvents the returns to scale restrictions.

An LR test was carried out to determine whether the inefficiency effects model was befitting for the data. This is usually done by checking whether the source of inefficiency is due to random error or inefficiency effects. The key parameter lying between zero and unity is given as:

$$\gamma = \sigma_u^2 / \sigma_u^2 + \sigma_v^2 \tag{6}$$

with the null hypothesis stating that $\gamma = 0$ which implies the absence of inefficiency effects that makes the estimation of the stochastic frontier unnecessary. This is because a traditional mean response function (ordinary least squares) provides an adequate representation of data in the absence of inefficiency effects (Battese and Coelli, 1995). The null hypothesis is strongly rejected ($\rho < 0.001$). Hence, inefficiency effects are present suggesting that an inefficiency effects model is appropriate for carrying out the estimations.

Following previous studies (Kumbhakar *et al.*, 2012; Kumbhakar and Lovell, 2003), explanatory variables (z) are introduced into Equation (5) to explain inefficiency with the assumption that $u_i \sim N^+\left(0,\ \sigma^2_{ui}\right)$ where σ^2_{ui} is specified as:

$$\sigma^2_{ui} = \delta_o + \sum_{j=1}^{J} \beta_j z_{j,i} \tag{7}$$

where $j = 1, 2, \ldots, J$ represents the explanatory variables in z including the independent variables of interest which are the innovation inputs comprising internal R&D, HCD, foreign technology adoption, and foreign ownership; and the control variables comprising age, size, export status, imports, external financing, access to credit, educational attainment, managerial experience, formal status, capacity utilisation, ICT infrastructure, informal competition, industry dummies, and country dummies. This study considers an inefficiency effects model investigating the effects of the innovation inputs including the interaction terms of foreign technology adoption and internal R&D, and foreign technology adoption and HCD, respectively. Thus, the inefficiency effects model analysed in this study is as follows:

$$u_i = \alpha + \beta_1 \mathrm{IRD}_i + \beta_2 \mathrm{HCD}_i + \beta_3 \mathrm{FT}_i + \beta_4 \mathrm{FO}_i + \beta_5 (\mathrm{FT}_i \times \mathrm{IRD}_i) + \beta_6 (\mathrm{FT}_i \times \mathrm{HCD}_i) + \phi' \mathrm{Controls}_i \tag{8}$$

where IRD_i represents internal R&D for firm i; HCD_i represents HCD for firm i; FT_i represents foreign technology adoption for firm i; FO_i represents foreign ownership for firm i; $\mathrm{FT}_i \times \mathrm{IRD}_i$ represents the interaction of foreign technology adoption and internal R&D, and $\mathrm{FT}_i \times \mathrm{HCD}_i$ represents the interaction of foreign technology adoption and HCD. $\mathrm{Controls}_i$ represents a vector of control variables including age, size, export status, imports, external financing, access to credit, educational attainment, managerial experience, formal status, capacity utilisation, ICT infrastructure, informal competition, industry dummies, and country dummies. The presence of observable but uncontrolled heterogeneity in u_i and v_i may affect the inference in stochastic frontier models (Kumbhakar and Lovell, 2003). Uncontrolled heteroscedasticity leads to biased inefficiency estimates (Belotti *et al.*, 2012). Equation (5), the baseline equation (Aigner *et al.*, 1977; Meeusen and van Den Broeck, 1977) has been extended such that the variance in the inefficiency term depends on the independent variables (z) and the noise term is allowed to be heteroscedastic due to variances arising from industry and country differences (Hadri, 1999).

4. Results

Table I provides descriptive statistics for the whole sample. About 26 per cent of the firms invest in internal R&D. In contrast, it can be observed that about 41 per cent of the firms undertook HCD involving formal training for employees. Furthermore, only 19 per cent of the firms in the sample adopt foreign technology. Similarly, only 17 per cent of the firms report foreign ownership. This suggests that HCD is a preferred option among the alternative innovation inputs. It is also observed that about 88 per cent of the firms report utilising at least 50 per cent of their capacity. Also, about 65 per cent of the employees in the sample possess secondary school education. Furthermore, about 60 per cent of the firms report having ICT infrastructure. Lastly, about 59 per cent of the firms fall in the low-technology industry.

The SFA approach constructs a frontier from efficient firms that envelopes relatively inefficient firms. Several assumptions are made. First, the production function is assumed to be valid for all firms. Second, production technology is assumed to be the same for all firms, implying that production technology is homogenous. Assumptions are also made about the functional form that the production function takes and the distributional form of the error term. The MML estimates of the SFA and the inefficiency effects model estimates arising from the estimation of Equation (5) subject to the specification of the inefficiency effects modelled in Equation (8) are shown in Tables II-III. Model 1 in Table II provides the results

Table I.
Descriptive statistics

	Variables	Mean	SD	Min	Max
1	ln(Output)	13.01	2.82	5.40	20.93
2	ln(Capital)	11.83	3.20	3.50	24.25
3	ln(Labour)	3.16	1.37	0.10	8.29
4	Internal R&D	0.26	0.44	0.00	1.00
5	Foreign technology adoption	0.19	0.40	0.00	1.00
6	Foreign ownership	0.17	0.37	0.00	1.00
7	HCD	0.41	0.49	0.00	1.00
8	Age	22.02	17.62	1.00	96.00
9	Size	0.50	0.50	0.00	1.00
10	Export status	0.18	0.39	0.00	1.00
11	Imports	32.88	38.82	0.00	100.00
12	External financing	0.28	0.45	0.00	1.00
13	Access to credit	0.33	0.47	0.00	1.00
14	Educational attainment	65.42	32.67	0.00	100.00
15	Managerial experience	0.57	0.50	0.00	1.00
16	Formal status	0.75	0.44	0.00	1.00
17	Capacity utilisation	0.88	0.33	0.00	1.00
18	ICT infrastructure	0.60	0.49	0.00	1.00
19	Informal competition	0.34	0.47	0.00	1.00
20	High-technology industry	0.17	0.37	0.00	1.00
21	Medium-technology industry	0.24	0.43	0.00	1.00
22	Low-technology industry	0.59	0.49	0.00	1.00
23	Ghana	0.14	0.34	0.00	1.00
24	DRC	0.17	0.38	0.00	1.00
25	Tanzania	0.07	0.26	0.00	1.00
26	Uganda	0.10	0.29	0.00	1.00
27	Zambia	0.19	0.39	0.00	1.00
28	Kenya	0.33	0.47	0.00	1.00

Note: $n = 418$

Table II.
Summary of maximum-likelihood regression coefficients of the SFA

Independent variables	Model 1
Determinants of inefficiency	
Innovation inputs	
Internal R&D (*H1*)	0.889** (0.394)
HCD (*H2*)	−0.131 (0.364)
Foreign technology adoption (*H3*)	1.362** (0.605)
Foreign ownership (*H4*)	−1.990*** (0.556)
Interactions	
Foreign technology adoption×internal R&D (*H5*)	−1.791* (1.028)
Foreign technology adoption×HCD (*H6*)	−1.698** (0.763)

Notes: $n = 418$. Robust standard errors in parentheses. $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$

showing the inefficiency effects arising from the main effects of innovation inputs, and the interaction effects of foreign technology adoption and internal R&D, and foreign technology adoption and HCD as well. In keeping with the tradition of reporting SFA coefficients, the interpretation provided for a positive sign on a coefficient in the inefficiency effects model is that the coefficient reflects increased firm inefficiency. Hence, a positive coefficient is reported as having a negative effect on technical efficiency. Contrastingly, a negative sign on a coefficient is interpreted as the coefficient having a decreasing effect firm inefficiency. Thus, a negative coefficient is interpreted as having a positive effect on technical efficiency.

Variables	Model 1
Frontier	
ln(Capital)	0.154 (0.172)
ln(Labour)	2.881*** (0.354)
$\ln(\text{Capital})^2$	0.016** (0.008)
$\ln(\text{Labour})^2$	−0.001 (0.057)
ln(Capital)×ln(Labour)	−0.121*** (0.033)
Constant	5.336*** (1.103)
Determinants of inefficiency	
Innovation inputs	
Internal R&D (*H1*)	0.889** (0.394)
HCD (*H2*)	−0.131 (0.364)
Foreign technology adoption (*H3*)	1.362** (0.605)
Foreign ownership (*H4*)	−1.990*** (0.556)
Interactions	
Foreign technology adoption×internal R&D (*H5*)	−1.791* (1.028)
Foreign technology adoption×HCD (*H6*)	−1.698** (0.763)
Control variables	
Age (log)	−0.438** (0.188)
Size	2.347*** (0.376)
Export status	−1.315 (1.141)
Imports	−0.002 (0.004)
External financing	−0.725* (0.383)
Access to credit	−0.501 (0.334)
Educational attainment	−0.008** (0.004)
Managerial experience	−0.020 (0.316)
Formal status	−0.347 (0.309)
Capacity utilisation	−0.842* (0.452)
ICT infrastructure	−1.240*** (0.404)
Informal competition	−0.655* (0.375)
Constant	2.608*** (0.711)
Heteroscedasticity	
High-technology industry	0.243 (0.370)
Medium-technology industry	0.503* (0.274)
Ghana	−0.469 (0.375)
DRC	0.452 (0.335)
Tanzania	0.034 (0.400)
Uganda	−0.081 (0.456)
Zambia	−0.914*** (0.347)
Constant	0.660** (0.281)

Notes: $n = 418$. Robust standard errors in parentheses. *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$

Table III. Maximum-likelihood regression coefficients of the SFA

Table III shows the full results of Model 1 including the stochastic frontier estimates, the inefficiency determinants, control variables coefficients, and the heteroscedasticity estimates.

Of particular interest are the estimates in the inefficiency effects model. Among the independent variables, the coefficient for internal R&D is positive and statistically significant. This result offers support for *H1* which proposes a significant relation between internal R&D and technical efficiency. Internal R&D therefore has a negative and significant relation with technical efficiency in the context of manufacturing firms in SSA. However, the coefficient for HCD is negative but statistically nonsignificant. This result offers no support for the *H2* proposing a positive relation between HCD and technical efficiency. Nevertheless, the coefficient for foreign technology adoption is positive and statistically significant. Foreign technology adoption has a negative and significant relation with technical efficiency in the context of manufacturing firms in SSA. This result offers support for *H3* which predicts a significant relation between foreign technology adoption and technical efficiency. The coefficient for foreign ownership is negative and statistically significant. Foreign ownership is therefore positively associated with technical efficiency. This result offers strong support for *H4*. Turning to the coefficients of the interaction terms (i.e. foreign technology adoption × internal R&D, and foreign technology adoption × HCD), it is found that both interacted coefficients are negative and statistically significant. These results provides strong support for *H5* which predicts that foreign technology adoption in combination with internal R&D amplify each other's effects on technical efficiency. Similarly, foreign technology adoption in combination with HCD amplify each other's effects on technical efficiency. This result also provides strong support for *H6*. Hence, combining foreign technology adoption with internal R&D and HCD yields positive efficiency effects.

The full results of Model 1 presented in Table III reveal that production inputs including capital and labour in the stochastic frontier estimation have positive coefficients as expected. Notwithstanding, only labour has statistically significant coefficients. This result underscores the importance of labour for productivity in the context of developing countries in SSA.

4.1 Robustness tests

Models 2-3 in Table IV shows the robustness of the results in Model 1 to excluding country dummies and industry dummies, respectively. The reported results reveal that internal R&D, foreign technology adoption, and the interaction terms are sensitive to the inclusion of country and industry dummies. This indicates that country differences and industry differences predominantly account for the variation in these innovation inputs. Thus, the efficiency effects of these innovation inputs and their interaction are only realised once country differences and industry differences are accounted for. Notwithstanding, the signs of the coefficients of interest remain unchanged. The main qualitative conclusions therefore remain the same. Further robustness tests were also conducted using an endogenous stochastic frontier model proposed by Karakaplan and Kutlu (2015) to test for possible endogeneity of internal R&D and export status. Table V shows the results of this test in Model 4 from which it can be observed that internal R&D and export status are not endogenous.

5. Discussion

The findings of this study primarily support the hypotheses. The negative and significant relation between internal R&D and technical efficiency is an important finding given the context of the study. Biggs (1995) argues that inefficiency in manufacturing firms in SSA is attributed to a lack of R&D spending and a lack of organised R&D activity. Hence, internal R&D is expected to bolster efficiency (Kumbhakar *et al.*, 2012). Nonetheless, this study reveals that internal R&D diminishes efficiency. There are several probable explanations for this anomalous result. First, internal R&D in a firm may lead to efficiency within the firm but results in relative inefficiency in firms not pursuing internal R&D resulting in overall inefficiency in an industry (Torii, 1992). Second, firms may engage in unproductive R&D that could result in wasteful practices which in turn result in inefficiency (Gumbau-Albert and Maudos, 2002). Another reason may be attributed to the fact that internal R&D may have dynamic effects such that current internal R&D may not influence efficiency in the current period but in future time periods (Gumbau-Albert and Maudos, 2002).

Foreign technology adoption is also found to have a negative and significant effect on technical efficiency. This finding may be attributed to firms adopting foreign technology that is inappropriate given the socio-economic and technological operational environment (Basu and Weil, 1998). Additionally, in this study context, there is a high likelihood that foreign technologies are sourced from relatively developed countries, and that these

Variables	Model 2	Model 3
Frontier		
ln(Capital)	0.591*** (0.177)	0.425* (0.220)
ln(Labour)	1.949*** (0.383)	2.205*** (0.368)
ln(Capital)^2	−0.009 (0.010)	0.0001 (0.010)
ln(Labour)^2	−0.045 (0.043)	−0.028 (0.043)
ln(Capital)×ln(Labour)	−0.030 (0.035)	−0.057** (0.029)
Constant	3.648*** (0.949)	4.415*** (1.294)
Determinants of inefficiency		
Innovation inputs		
Internal R&D (*H1*)	0.589* (0.338)	0.688 (0.543)
HCD (*H2*)	−0.002 (0.333)	−0.157 (0.565)
Foreign technology adoption (*H3*)	0.470 (0.588)	0.755 (0.963)
Foreign ownership (*H4*)	−2.936*** (0.630)	−2.637*** (0.912)
Interactions		
Foreign technology adoption×internal R&D (*H5*)	−0.359 (0.826)	−0.971 (1.318)
Foreign technology adoption×HCD (*H6*)	−1.160 (0.764)	−0.781 (0.873)
Control variables		
Age (log)	−0.077 (0.172)	−0.201 (0.217)
Size	1.385*** (0.314)	1.508*** (0.371)
Export status	−1.500* (0.817)	−1.594 (3.735)
Imports	−0.002 (0.004)	−0.003 (0.005)
External financing	−0.669* (0.360)	−0.529 (0.555)
Access to credit	−0.367 (0.307)	−0.440 (0.384)
Educational attainment	0.001 (0.004)	−0.002 (0.005)
Managerial experience	−0.097 (0.290)	−0.126 (0.439)
Formal status	−0.215 (0.291)	−0.349 (0.381)
Capacity utilisation	−0.057 (0.461)	−0.335 (0.571)
ICT infrastructure	−0.812** (0.319)	−0.984** (0.445)
Informal competition	−0.308 (0.335)	−0.583 (0.571)
Constant	0.697 (0.736)	1.318 (1.023)
Heteroscedasticity		
High-technology industry	0.123 (0.433)	
Medium-technology industry	0.036 (0.328)	
Ghana		−0.100 (0.493)
DRC		0.390 (0.402)
Tanzania		0.087 (0.484)
Uganda		0.094 (0.474)
Zambia		−0.441 (0.563)
Constant	0.363* (0.213)	0.507 (0.402)

Notes: $n = 418$. Robust standard errors in parentheses. *$p < 0.10$; **$p < 0.05$; ***$p < 0.01$

Table IV. Robustness checks using the maximum-likelihood regression coefficients of the SFA

technologies were developed to make optimal use of the factor endowment of the originating countries. Hence, given the factor endowment disparities between developed countries and developing countries particularly in the context of SSA, it is very likely that the adoption of such technologies undermines efficiency (Acemoglu, 2002). In addition, developing countries are characterised by an abundance of semi-skilled and unskilled labour, which impedes efficient use of the technology embedded in foreign technologies (Fu *et al.*, 2011). In contrast, the results of this study show that there exists a positive relation between foreign ownership and technical efficiency. This finding indicates that foreign ownership ameliorates inefficiency in manufacturing firms in SSA. Foreign direct investment is an important source of embodied technology for manufacturing firms in SSA. The positive efficiency

Variables	Model 4
Frontier	
ln(Capital)	0.332 (0.180)
ln(Labour)	2.238*** (0.309)
ln(Capital)2	0.002 (0.008)
ln(Labour)2	−0.04 (0.043)
ln(Capital)×ln(Labour)	−0.051* (0.025)
Constant	4.896*** (1.127)
Determinants of inefficiency	
Innovation inputs	
Internal R&D (*H1*)	0.366 (0.652)
HCD (*H2*)	−0.007 (0.459)
Foreign technology adoption (*H3*)	1.325* (0.605)
Foreign ownership (*H4*)	−10.256** (3.539)
Interaction effects	
Foreign technology adoption×Internal R&D (*H5*)	−1.235 (0.826)
Foreign technology adoption×HCD (*H6*)	−0.515 (0.761)
Control variables	
Age (log)	−0.344 (0.254)
Size	2.364*** (0.544)
Export status	−14.131*** (1.770)
Imports	−0.001 (0.005)
External financing	−0.391 (0.469)
Access to credit	−0.350 (0.402)
Educational attainment	−0.002 (0.005)
Managerial experience	−0.003 (0.382)
Formal status	−0.681 (0.380)
Capacity utilisation	−0.628 (0.521)
ICT infrastructure	−1.376** (0.475)
Informal competition	−0.761 (0.546)
Constant	1.881* (0.847)
Heteroscedasticity	
High-technology industry	−0.058 (0.334)
Medium-technology industry	0.174 (0.266)
Ghana	−0.590 (0.418)
DRC	0.253 (0.304)
Tanzania	−0.432 (0.378)
Uganda	−0.223 (0.366)
Zambia	−0.943** (0.353)
Constant	0.858*** (0.236)
η1 (Export status)	−0.13 (0.326)
η2 (Internal R&D)	−0.31 (0.330)
η Endogeneity test (F-Stat = 1.03)	$p = 0.598$
Log Likelihood	−1,105.100
Mean prod efficiency	0.668
Median prod efficiency	0.641

Notes: $n = 418$. Standard errors are in parentheses. R&D activities and export status are possibly endogenous. Karakaplan and Kutlu (2015) propose a test for endogeneity of the inefficiency term that relies on the joint significance of the components of the η term. In this test, a variable is endogenous if its respective corresponding component of the η term is significant (www.mukarakaplan.com). Application for patent for product innovation, and application to obtain an import licence were used for instrumenting internal R&D and export status, respectively. These instruments satisfied the $F > 10$ rule of thumb. This test revealed that internal R&D and export status were not endogenous. Additionally, the components were not jointly significant. Hence, this study reports inefficiency effects estimates obtained from the traditional frontier models. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Table V.
Robustness checks using an endogenous stochastic frontier

effect arising from foreign ownership is most probably a result of foreign direct investment encompassing the transfer of human capital and employee training opportunities (Borensztein *et al.*, 1998). Hence, the transfer of human capital and employee training arising from foreign ownership are instrumental for enhancing efficiency in the context of developing countries in SSA.

The study findings also provide evidence that the adoption of foreign technology in combination with internal R&D reinforce each other's effects on technical efficiency. Previous studies argue that there exists a degree of complementarity between internal R&D and the adoption of foreign technology (Chang and Robin, 2006; Fu *et al.*, 2011) since successful adoption of foreign technology depends on the degree absorptive capacity of a firm, which in turn depends on internal R&D and HCD (Crespi and Zuniga, 2012; Griffith *et al.*, 2003). Thus, the adoption of foreign technology is conditioned on internal R&D that is "absorptive" in nature. In addition, it has been argued that investing in either internal R&D or the adoption of foreign technology does not yield optimal efficiency gains for developing countries (Fu and Gong, 2011; Rifkin, 1975). The study findings therefore suggest that in the context of manufacturing firms in SSA, efficiency gains are only realised from combining foreign technology adoption with internal R&D.

Moreover, the study findings reveal that foreign technology adoption in combination with HCD also strengthen each other's effects on technical efficiency. Thus, foreign technology adoption does not result in efficiency gains intrinsically because foreign technology performance is conditioned on the degree of absorptive capacity in a firm. A distinctive feature of developing countries in SSA is the abundance of semi-skilled and unskilled labour. Hence, this study puts forward that building absorptive capacity by means of HCD programs is critical for successful adoption of foreign technology in the context of SSA (Bronzini and Piselli, 2009; Griffith *et al.*, 2004). Formal training programs are therefore central to successful adoption of foreign technology that results in efficiency gains because workers are better able to assimilate new technologies in the production processes(Blundell *et al.*, 1999; Madsen *et al.*, 2010).

The main theoretical implication arising from the study findings is that building absorptive capacity in firms is vital for enhancing technical efficiency. Essentially, absorptive capacity involving the assimilation of external technological knowledge that is valuable for successful adoption of foreign technology is critical for realising efficiency gains in SSA. Although internal organisational innovation inputs including internal R&D and HCD have traditionally received considerable attention, the link between these two inputs and external innovation inputs encompassing foreign technology adoption has typically been overlooked especially at the firm-level. Thus, extending the absorptive capacity theory in the context of internal and external innovation inputs yields fruitful insights regarding technical efficiency in the context of SSA. This is especially important because it is evident that the adoption of foreign technology is conditioned on the degree of absorptive capacity, which results in efficiency gains in manufacturing firms in developing countries in SSA. This may be attributed to the fact that these two facets of absorptive capacity including internal R&D and HCD are pivotal for building knowledge resources, and updating employee skills. This is a critical finding because a lack of organised R&D, and an abundance of semi-skilled and unskilled labour (Biggs, 1995) are among the most salient features of firms in SSA.

5.1 Managerial implications

Empirical evidence from this study reveals that investing in the adoption of foreign technology in isolation from internal R&D impedes technical efficiency in the context of manufacturing firms in SSA. Correspondingly, adoption of foreign technology in isolation from HCD impedes technical efficiency as well. Thus, building absorptive capacity within firms adopting foreign technology is likely to promote efficiency. Furthermore, given that lack of formal R&D is a distinctive feature in manufacturing firms in SSA, programs focussing on stimulating R&D investment within the firm are likely increase the degree of absorptive capacity on the overall. In light of this, it is important that managers focus on developing an R&D strategy that places emphasis on enhancing absorptive capacity. It is also important that managers focus on fostering appropriate "absorptive" R&D expenditure for firms using foreign technology in the manufacturing industry for increased and sustained efficiency. Furthermore, managers should develop R&D strategies that exploit incentives such as tax credits or subsidies on R&D expenditure since internal R&D is likely to foster "absorptive" R&D activities.

Additionally, investment in HCD programs such as on-the-job training is vital for building absorptive capacity by means equipping workers with new knowledge and skills. Consequently, firms engaging workers in formal training are likely reap efficiency gains. Also, the finding that foreign ownership promotes efficiency indicates that foreign direct investment plays a key role in boosting efficiency the context of manufacturing firms in SSA. Hence, this study contends that the absorptive nature of foreign direct investment is elemental in improving efficiency in manufacturing firms in SSA and suggest that managers in foreign-owned firms take advantage of existing foreign direct investment policies that may include corporate tax incentives that are suited to the macroeconomic environment of the host country. Accordingly, utilising tax incentives favouring the importation of capital goods from host countries, including policies facilitating the transfer of human capital from host countries is also likely to be instrumental in fostering efficiency.

In view of the managerial implications, we argue that it is imperative that firms in SSA need to consciously develop sound absorptive capacity strategies that revolve around internal R&D and HCD particularly for firms adopting foreign technology. This is underscored by the fact that the degree of absorptive capacity is conditioned on these innovation inputs, which result in efficiency gains when combined with foreign technology adoption in SSA.

6. Conclusion

In response to the question "How do innovation inputs affect technical efficiency in manufacturing firms in SSA?" this paper empirically examined the technical efficiency effects of innovation inputs. Notwithstanding the limitations of this paper, its findings offer valuable insights on the relationship between innovation inputs and technical efficiency in the context of manufacturing firms in SSA.

In sum, the positive and significant efficiency effects of combining foreign technology adoption with internal R&D, and HCD, respectively, indicates that investing in these sets of innovation inputs is conducive to mitigating inefficiency in manufacturing firms in Africa. This is especially true in this study context given that there is evidence of a negative association between internal R&D and efficiency, and foreign technology adoption and efficiency as well. This study argues that foreign technology may not be suited to the socio-economic and technological environment found in developing countries, yet if internal R&D is absorptive in nature, such technology can be adapted or modified to suit the specific needs of firms in developing countries resulting in increased efficiency. Equivalently, one may expect to see amplified efficiency gains when foreign technology adoption is coupled with HCD in developing countries. Hence, policies focussing on the development of human capital are crucial for promoting efficiency in manufacturing firms in developing countries. Lastly government policies focussing on industrialisation are more likely to yield efficiency gains if concerted effort is directed towards building the absorptive capacity of firms by facilitating internal R&D and HCD. This is particularly important in the context of developing countries because policy makers acknowledge that a strong human capital base plays a vital role in complementing investments and policies aimed at boosting productivity and efficiency.

This study has several limitations that open up avenues for future research. The first limitation relates to the analysis of firms in the manufacturing sector only in spite of the importance of the service sector being underscored in recent times. Hence, further studies examining technical efficiency effects in the service sector are much needed since the service sector has received considerably less attention in the past. The second limitation is that this study does not consider the possible effects of the geographical and institutional environment of firms yet their importance in driving efficiency has been emphasised in the context of SSA. The third limitation revolves around the lack of continuous data relating to monetary values of investments in internal R&D, HCD, and foreign technology adoption. This study relies heavily on dummy variables. Hence, there are no insights on rates or level of investment in innovation inputs that are discussed.

Further studies also depend on the availability of comprehensive panel data, which would enable extensive investigation of causal effects of innovation inputs on technical efficiency. This is due to the fact that the geographical environment and national policies generally differ across countries in Africa. Panel data methods would be useful in controlling for such heterogeneity and determining causal relationships that allow for a more conclusive interpretation of findings.

Notes

1. The authors acknowledge the possibility of a confounding effect given that this study uses cross-section data. In principle, current and lagged values of internal R&D and adoption of foreign technology should be included in the regressions of this study but this was not possible due to the nature of the data used in the analysis. In addition, internal R&D is a flow variable found in the IFS questionnaire while the adoption of foreign technology is a stock variable in the WBES questionnaire. Nevertheless, Crépon *et al.* (1998) argue that there is a high cross-sectional correlation between stock and flow measures of innovation inputs.
2. Instead of being taken a source of foreign technology, imports are used as a control variable because the WBES does not provide information on whether imported inputs convey embodied technology.

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