ABSTRACT

The role of agricultural technology is important in developing countries. However, in many cases the adoption rate of modern agricultural technology by smallholder farmers is low. Therefore, a better understanding of agricultural technology adoption determinants is important as a major component of agricultural growth. This paper is a review and synthesis of the literature related to potential factors that may constrain or encourage smallholder farmer adoption of new agricultural technologies. The determinant factors influencing smallholder farmer adoption of new technologies in developing countries vary from study to study based on contextual applicability and specific local condition. There are four major typologies of determinant factors are identified to help explain low adoption rates of particular agricultural technology in developing countries which are: technology attributes, farmer or farm household characteristics, farm characteristics and institutional factors. Future policy recommendations on adoption decision should consider all those four important factors to provide better understanding of new agricultural technology adoption by smallholder farmers, resulting in improved livelihoods for smallholders.

Keywords: Agricultural, technology, adoption, farmer

INTRODUCTION

Agricultural technology adoption in developing countries is important to enhancing agricultural productivity for food security and poverty alleviation (World Bank 2007). Adoption of agricultural technology is also a fundamental driving force for economic development (Barrett et al. 2010; Foster and Rosenzweig, 2010). For a long period of time, there are many new or improved agricultural technologies has been developed as one of the most important factors that would contribute to increase agricultural production (Monu, 1995). In the case of this paper, it is important to remind the reader that the term “agricultural technology” refers not only agricultural machinery, but also new crops (e.g. horticulture) and improved varieties of crops (e.g. hybrid seed, high-yielding varieties), farming systems (e.g. organic farming, sustainable agricultural practices-SAP), post-harvest practices/activities (e.g. marketing channel choices, drying technology), smart agricultural technologies (e.g. robots, sensors), and other agricultural innovations (e.g. information and communication technologies-ICTs, silage methods, fertilizer, crop insurance).

However, in many cases the adoption rate of agricultural technology (new/improved/modern) is low. For example, a recent study by Suprehatin (2019) in Indonesia show that there were relatively low adoption rates (10%) of new horticultural crops amongst
smallholder farmers across Java Island. This means that the majority of smallholder farmers continue to rely on their traditional cropping patterns or farming practices. In general, millions of smallholder farmers developing countries also remain in the lack of use improved technologies. This raises an important question why smallholder farmers in developing countries are not improving productivity by adopting a greater number of improved agricultural technologies. On the other hand, the agricultural sector in developing countries remains a central sector of the economy and agricultural technologies is the key to the agricultural growth.

Therefore, one of the major challenge for policy makers and practitioners to improve agricultural productivity is to increase the adoption rate of improved/innovative technologies for smallholder farmers. This is because not all smallholder farmers are able and willing to adopt new agricultural technologies because of the challenges and constraints to adoption imposed by various different factors. There is a long and rich tradition of empirical studies that seeking an explanation to smallholder farmers’ adoption of particular agricultural technologies or innovations. These studies have covered a wide range of new agricultural technologies or innovations from new/improved input technologies to information and communication (smart) agricultural technologies. Thus, this paper aims to provide a review and synthesis of the numerous studies that have examined smallholder farmer adoption of different agricultural technologies in developing countries. More specifically, the paper aims (1) to describe different types of agricultural technology adoption, (2) to analyze determinant factors of agricultural technology adoption and (3) to explore agricultural technology adoption and its policy recommendations for Indonesia.

The study used a desk study approach by reviewing the previous adoption studies of different agricultural technologies in developing countries. This review adopted partially a scoping review methodology framework developed by Arksey and O’Malley (2005) to allow the researcher to engage with a wider literature on the relevant studies. The steps are as follows: First, identifying the research questions. The research questions of this study are: what is known from existing literature about the types of new agricultural technologies adopted by smallholder farmer adoption in developing countries? What the determinants factors that significantly influencing smallholder farmer adoption of these new agricultural technologies?

Second, searching and identifying relevant studies used the following bibliographic databases: Google scholar and Science Direct. The main keyword search related to the review topic used in this study were adoption/application/participation, agricultural technologies/innovations, smallholder farmers/farmers, and determinants/factors. As a result, this desk study reviewed more than 60 literatures including seminal works and studies that have summarized previous adoption literature (Doss 2006; Feder et al. 1985; Knowler and Bradshaw 2007; Prokopy et al. 2008; Rogers 2003). The process involves two following tasks which were a review of the context of adoption and a review of significant factors. The significant variables were identified among the numerous studies that have examined farmer adoption of different agricultural technologies.

Third, summarising and reporting. A thematic analysis was conducted to summarize and analyze findings from research on both types of agricultural technologies/innovations and important factors affecting smallholder farmer adoption.

DIFFERENT TYPES OF AGRICULTURAL TECHNOLOGY ADOPTION

As explained previously, the role of improved agricultural technology is important in developing countries. This section reviews the literature related to different types of agricultural technologies adoption by smallholder farmers.

In terms of different types of agricultural technology adoption, the previous empirical studies have covered a wide range of new agricultural technologies or innovations from new/improved input technologies to information and communication (smart) agricultural technologies. First, the majority of adoption studies conducted in developing countries have focused on adoption of improved or new agricultural input technologies by smallholder farmers. These innovations relate to new/modern/improved input technologies, such as high yield crop varieties including hybrid seed (Asfaw et al. 2012; Fisher and Kandiwa 2014; Kuntariningsih and Mariyono 2013; Matuschke and Qaim 2009), pesticides (Abdollahzadeh et al. 2015; Abebaw and Haile 2013), fertilizers (Krishnan and Patnam 2014; Lambrecht et al. 2014; Yu and Nin-Pratt 2014) and agricultural machinery, including tractors (Cunguara and Darnhofer 2011; Pingali 2007). Most existing studies have focused on adoption of new agricultural technologies to improve productivity of staple crops, such as hybrid rice and maize varieties (Ghimire and Huang 2015; Khonje et al. 2015; Mathenge et al. 2014). Most studies examined adoption of individual technologies in specific production zones that have been promoted by governments to encourage greater production of staple food crops.

Second, many studies on new farming system technologies, such as integrated pest management (IPM) techniques and organic farming, have focused on sustainability of staple food crop production. Such studies have examined new/modern farming systems or production practices, such as organic farming (Hossain et al. 2007; Pornpratansombat et al. 2011; Wollni and Andersson 2014), IPM (Mariano et al. 2012; Parsa et al.)
Determinants of agricultural technology adoption ... (Suprehatin)

Previous studies have examined agricultural technology adoption. However, in many cases the adoption rate of modern agricultural technologies is low. Therefore, a better understanding of agricultural technology adoption determinants is important as a major component of agricultural growth (Foster and Rosenzweig 2010). This section reviews the literature related to potential factors that may constrain or encourage smallholder adoption of new agricultural technologies.

In terms of determinant factors of adoption, an extensive strand of the empirical literature has addressed determinant factors of agricultural technology adoption. On the other hand, there are also seminal works and studies that have summarised previous adoption literature (e.g. Doss 2006; Feder et al. 1985; Knowler and Bradshaw 2007; Prokopy et al. 2008; Rogers 2003). In addition, there is also another seminal work and study that proposed farmer types and adaptations of Ajzen’s Theory of Planned Behaviour or attitudes as a different approach to the study of adoption of agricultural technology (see Ajzen 1991; Morrison et al. 2012). Drawing on these seminal works and empirical studies, four major typologies of factor characteristics are identified to help explain low adoption rates of particular agricultural technology, particularly in developing countries. These are technology attributes (e.g. higher expected profit, less labour required), farmer or farm household characteristics (e.g. age, education, household assets), farm characteristics (e.g. farm size, land tenure) and institutional factors (e.g. credit constraints, market access). Each of the four factors are discussed below.

**Technology Attributes**

A given agricultural technology or innovation embodies a number of important attributes that may influence adoption decisions. Important work by Rogers in 1962 introduced five attributes of innovations to help in assessing different rates of adoption (Rogers 2003). Those attributes were relative advantage, compatibility, complexity, trialability and observability. After Rogers (2003), Fliegel and Kivlin (1966), Tornatzky and Klein (1982), and Moore and Benbasat (1991) addressed more than 25 attributes of innovations, such as cost, communicability, social approval and visibility, rather than Rogers’ innovation attributes. These studies proposed better understanding of the effects of technology attributes as they significantly influence adoption of technology or innovation. However, only Rogers (2003) and Fliegel and Kivlin (1966) focused on agricultural technology attributes.

Previous studies have examined the effects of technology attributes on farmer adoption decisions (e.g. Adesina and Zinnah, 1993; Batz et al. 1999; Hintze et al. 2003; Lunduka et al. 2012). Adesina and Zinnah (1993) showed that farmer perceptions of attributes of modern rice varieties significantly influence adoption decisions in Sierra Leone. Batz et al. (1999) revealed that relative complexity and risk of agricultural technologies are important factors in farmer adoption in Kenya. Hintze et al. (2003) found varietal attributes are significant factors contributing to low levels of adoption of improved maize varieties in Honduras. Birol et al. (2009) identified the significant role of farmer perceptions of technology attributes on adoption decision-making in Mexico. Another study by Lunduka et al. (2012) demonstrated that specific attributes of different maize varieties are an important factor for farmer adoption in Malawi. Indeed, these studies show the importance of farmer preferences...
for attributes of new agricultural technologies on adoption behaviour.

The studies under discussion used a different approach from this study to elicit farmer preferences for technology attributes. Adesina and Zinnah (1993) used a farmer subjective assessment to measure dichotomous scales, in terms of yes or no, of preferences for technology attributes. Similarly, Lunduka et al. (2012) applied dichotomous questions to examine farmer preferences for modern maize varietal attributes. Batz et al. (1999) employed a scoring approach which involved assessments made by extension workers in the study area. Hintze et al. (2003) applied a rating method to each variety using a three-scale method of very good/good, regular/average/sufficient and bad. In summary, those approaches may have potential weaknesses. For dichotomous scales, respondents are required to choose a response that does not exactly reflect their answer and the researcher cannot further explore response meaning. A rating scale may create median responses which often occur in ranking and rating methods (Balcombe et al. 2014). Recent studies used the innovative method of best-worst (BW) scaling to elicit farmer preferences for technology attributes (e.g. Ochieng and Hobbs 2016; Umberger et al. 2015). A benefit of this method over others is that respondents choose both the best and worst attributes and are forced to make trade-offs amongst subsets of crop attributes. According to (Vermeulen et al. 2010), BW scaling yields considerably more information about individuals’ preferences compared to traditional choice methods. As discussed above, studies on farmer preferences for technologies and technology attributes should be considered when investigating farmers’ needs when making adoption decisions. In addition, farmer needs could be indicative of constraints in adopting new agricultural technology.

Farmer and Farm Household Characteristics

The importance of farmer characteristics in agricultural technology adoption has been widely acknowledged. The broad literature on agricultural technology adoption has suggested three key farmer (or farm household) characteristics that influence adoption of agricultural technology. These factors are human capital, household assets and financial capital. According to the literature, the importance of each factor and direction of influence depends on the nature of the technology (Doss 2006; Feder et al. 1985; Knowler and Bradshaw 2007).

Human capital, such as education, experience, age, and family labour availability, have emerged as variables that potentially influence adoption of improved technologies (Feder et al. 1985; Knowler and Bradshaw 2007). More highly educated farmers are more likely to adopt new agricultural technologies faster, particularly for knowledge-intensive technologies. For example, empirical studies by Rao and Qaim (2011) and Sahara et al. (2015) proposed that education is positively correlated with adoption of new modern market-channels, which often require substantial changes in traditional practices. Similarly, more experienced farmers tend to adopt new agricultural technologies (e.g. Kabunga et al. 2012). A previous study by Ainembabazi and Mugisha (2014) in Uganda found that experience relates positively to adoption of bananas and maize in the early stages of adoption. A younger farmer also tends to be a potential adopter of new agricultural technologies (e.g. Adesina et al. 2000; Nkonya et al. 1997; Suprehatin 2019). Household availability of labour required for adoption is also important. Horticultural crop technologies, for example, are often more labor-intensive, so their adoption depends on family labour availability (Joshi et al. 2006; Minot and Roy 2007).

Household assets can also influence adoption of new agricultural technologies. Assets deal with whether farmers have the requisite physical (material) essentials for agricultural technology adoption. Productive assets, such as transportation (e.g. a motorbike), agricultural production (e.g. water pump, sprayer and tractor) and storage assets, are commonly captured in studies on agricultural technology adoption (e.g. Feder et al. 1985; Suprehatin 2019; Wahida 2015). Productive assets are assumed to be positively related to adoption decisions and innovativeness of a farm household (Feder et al. 1985). If a farm household has more assets, it may easier to cope with drawbacks from unsuccessful agricultural technology adoption.

Another farm household characteristic that may play an important role in agricultural technology adoption is financial capital. Farmers are often constrained regarding access to financial resources, such as credit and off-farm incomes (Doss 2006). Finance-constrained farmers are more likely to show slow and low adoption of agricultural technologies, particularly when large investments and inputs are required (Doss 2006; Pannell et al. 2006). As explained above, farmer and farm household characteristics are important factors in adoption decision. Therefore, future studies should include farm household characteristics in modelling agricultural technology adoption.

Farm Characteristics

The third important factor in adoption of new agricultural technology is farm characteristics. A large body of literature attempts to explain farm characteristics of decision-makers (farmers) that tend to increase agricultural technology adoption. These factors include farm size, land tenure, type of irrigation land, land ownership structure and supply of complementary farming inputs (Feder et al. 1985; Knowler and Bradshaw
Determinants of agricultural technology adoption in Indonesia

2007). Knowler and Bradshaw’s (2007) study concluded that farm size and land tenure (leased) appeared to have different impacts on agriculture technology adoption. However, farm size is often found to significantly influence adoption of agricultural technologies. In addition, in their review, Feder et al. (1985) cited several studies that conclude that landowners are less likely than renters to adopt conservation practices such as conservation tillage and contour farming.

Modern agricultural technologies such as smart agricultural practices, agricultural ICT, and post-harvest technologies may involve constraints related to farm characteristics, particularly those of smallholder farmers. They are often unable to bear larger investment, such as land required to produce high value agricultural crops. Therefore, future studies should consider farm characteristics, such as farm size and land tenure, in examining agricultural technology adoption.

**Institutional Factors**

Institutional factors can influence farmer decisions to adopt new agricultural technologies. From an extensive review of literature on agricultural technology adoption by Doss (2006) and Feder et al. (1985), institutional factors include exposure of extension services, availability of information on new technologies and accessibility of markets for products and inputs. Many studies are concerned with these factors which influence farmer adoption of agricultural technologies and result in various impacts (e.g. Kabunga et al. 2012; Krishnan and Patnam 2014; Moser and Barrett 2006). However, institutional constraints could generally be a problem for smallholder farmers in adoption of agricultural technologies in developing countries, particularly when the technology is new and not widely known (Feder et al. 1985). Another institutional factor that is important to agricultural technology adoption is farmer membership in producer organizations. An empirical study Abebaw and Haile (2013) found that membership in farmer cooperatives has a significant effect on adoption of chemical fertilisers and improved seeds. The result is also in line with a recent study by Suprehatin (2019) which show producer organizations and farmer field school (FFS) make effective contribution to new horticultural crop adoption in Indonesia.

Beyond farm, farmer, and household characteristics, external factors can also be important to adoption of new agricultural technologies. These include government policy (e.g. subsidies), infrastructure (e.g. distance to road, distance to markets) and agro-ecological zones (e.g. elevation) (Basu and Qaim 2007; Doss 2006; Feder et al. 1985; Fisher and Kandiwa 2014). In addition, another strand of literature also explores social network, ambiguity, trust and communication (see Barham et al. 2014; Breetz et al. 2005; Maertens and Barrett 2013; Morrison et al. 2011) as important factors of agricultural technology adoption.

**AGRICULTURAL TECHNOLOGY ADOPTION IN INDONESIA**

In Indonesia, like in many developing countries, agricultural technology plays a vital role to increased productivity and was successful during the first Green Revolution as supported by appropriate policy support, high rates of investment in crop research, infrastructure and market development (Pingali 2012). As discussed above, most adoption studies including in Indonesia examined adoption of an individual farm technology in a specific geographical area. Such studies have explored different types of agricultural technology adoption among Indonesian smallholder farmers included along the continuum of new agricultural technologies from improved input technologies to market channels. The type of agricultural technologies included varieties or crops, farming practices or techniques, tools or equipment, know-how and skills, information and communication technologies or combinations of the aforementioned components.

Current agricultural inputs technologies have been promoted by Indonesian government, industries or universities such as improved varieties (e.g. true seed shallots, rice variety IPB 3S) and fertiliser (e.g. organic fertilizer, cocoa-specific NPK fertiliser). In 2019, Ministry of Agriculture (MoA) has launched the improved rice varieties that known as functional rice (food) such as Baroma, Pamelen, Pamera, Paketih, Jeliteng, Inpari IR Nutri Zinc, Sembada Hitam, and Sembada Merah with potential harvest more than 9 ton per ha. This means that agricultural technologies are developed for improving both food and nutrition security. Indonesian government also encourage farmers to adopt or participate in agricultural insurance such as rice insurance (AUTP) and livestock insurance (AUTS) to protect smallholder farmers from failure. Other current agricultural technologies have also been introduced for Indonesian farmers: farming practices (e.g. organic farming, jajar legowo, climate smart agriculture, smart farming), post-harvest operations and processing technologies (e.g. threshers, drying technologies, controlled atmosphere storage), ICTs (e.g. mobile phones, mobile applications, internet), improved marketing practices (e.g. contract farming, supermarket channels, e-commerce channels).

The types of agricultural technology adoption in Indonesia also vary from study to study based on applicability and specific local conditions and needs. In other words, the agricultural technology adopted by Indonesian smallholder farmers varied and developed based on the development and availability of agricultural technologies. Those agricultural technologies have been promoted by governments, industries, universities,
research centres, NGO and other stakeholders to enhance agricultural productivity and livelihoods of Indonesian farmers. However, smallholder farmers in Indonesia is often still practised their farming activities without the benefit of modern tools or improved seed varieties (FAO 2018). It means that, although there were many new agricultural technologies has been launched and promoted but the rate of adoption of these technologies has remained low in Indonesia such as in horticultural crop adoption (see Suprehatin 2019). Therefore, there may be opportunities for policy makers to support smallholder farmers to adopt new/improved agricultural technologies for their own benefit and for the benefit of national agriculture as a whole.

POLICY RECOMMENDATIONS TO FOSTER AGRICULTURAL TECHNOLOGY ADOPTION IN INDONESIA

As discussed above, the previous extensive empirical studies have contributed to the existing literature by highlighting specific factors which influence the farmers’ decision to adopt a new horticultural crop. Based on critical examination of adoption literature, characteristics of farmer (or farm household), farm, institutional and technology are among the most important determinants of agricultural technology adoption. However, some studies have focused exclusively on characteristics of farmers, farm and institutional factors, while other studies focused on attributes of technology. Few studies have attempted to integrate technology attributes, socio-economic and institutional factors shown in previous research to be determinants of adoption. Several studies have been conducted to integrate drivers and preferences that farmers place on technology attributes (e.g. Adesina and Baidu-Forson 1995; Batz et al. 1999; Hintze et al. 2003; Useche et al. 2009).

Therefore, future studies and policy recommendations on adoption decision should consider all four important factors as discussed above. This integrated adoption model (Figure 1) is expected to provide better understanding of new agricultural technology adoption by smallholder farmers, resulting in improved livelihoods for smallholders. While some smallholder farmers have the potential to successfully adopt a new agricultural technology, others may not. Therefore, based on the results from the findings from the literature review as discussed above, a number of policy recommendations could be considered to foster adoption of new agricultural technologies among Indonesian smallholder farmers.

First, policy makers and practitioners may consider four major groups of important factors influencing agricultural technology adoption such as technology, farmer (farm household), farm and institutional characteristics (Figure 1). In other words, examining these diverse important factors is essential since it might directly impinge on the primary drivers for the adoption of improved agricultural technologies. For practitioners (e.g. agricultural input companies, digital platform-based companies), it will inform practical interventions and marketing strategies required to improve smallholder farmers’ adoption of new agricultural technologies and ultimately, secure their livelihood and welfare. For example, in terms of adoption (participation) on marketing channels, it will be more comprehensive understanding of market choice decision facing smallholder farmers in Indonesia. Among the four main of important factors, Indonesian policy makers and practitioners needs to analysis which significant factors influence Indonesian smallholder farmers’ decision whether to sell their products in different markets.

Second, understanding these diverse determinants of agricultural technology adoption allow policy makers and practitioners to targeting groups of farmers rather than all farmers to promote new agricultural technology adoption. In other words, not all programming and marketing strategies works similarly for all Indonesian smallholder farmers. For example, many previous empirical findings showed that younger farmers are more likely to adopt agricultural technologies (e.g. Adesina et al. 2000; Nkonya et al. 1997; Suprehatin 2019). Therefore, policy makers needs to develop tailored strategies to target Indonesian young farmer to adopt new agricultural technologies earlier. Another example, promoting policies that improve access to credit for certain groups of Indonesian farmers may be important as this was found to facilitate adoption of new agricultural technologies. However, the viability of these group of farmers needs to be assessed properly before the credit is provided.

Third, policies to promote and improve access to agricultural education and trainings for Indonesian smallholder farmers is important based on the previous findings that education facilitate agricultural technology adoption in Indonesia (Sahara et al. 2015; Suprehatin, 2019). The development of vocational institutions and training programs that focus on particular aspects of farming in certain agricultural areas could be an option for improving knowledge and skills of farmers. However, the programs should be developed based on the needs of farmers and can be linked to research and educational institutions (e.g. universities) and private sector. Therefore, it is important to bolster innovation and investment from the private sector for adoption of agriculture technologies.

Fourth, policy makers need to develop institutional innovations to facilitate smallholder farmers to appropriate agricultural technologies as this critical to foster its adoption. For example, through institutional arrangements, smallholder farmers may be able to
participate in the new modern market channels which offer the opportunities to get higher productivity and income (see Narayanan 2014; Rao and Qaim 2011; Sahara et al. 2015).

Fifth, policy makers may consider the technology characteristics or traits (see Batz et al. 1999; Hintze et al. 2003; Lunduka et al. 2012; Rogers 2003) by designing incentives and information on specific technology attributes that are most likely to encourage farmers to adopt new agricultural technologies that have a high probability of offering benefits. Therefore, policy makers will have a better understanding of how to achieve sound agricultural policy for smallholder farmers and economic development as a entirety.

CONCLUSIONS

The results of literature review show that determinant factors influencing smallholder farmer adoption of new technologies in developing countries vary from study to study based on contextual applicability and specific local condition. The results of literature study also have successfully indicated that there are four major typologies of determinant factors are identified to help explain low adoption rates of particular agricultural technology in developing countries which are technology attributes, farmer or farm household characteristics, farm characteristics and institutional factors. Furthermore, the results provide perspectives and prospects of agricultural technology adoption in Indonesia in terms of to targeting groups of farmers rather than all farmers, to promote and improve access to agricultural education and trainings for Indonesian smallholder farmers and to develop institutional innovations to facilitate smallholder farmers to appropriate agricultural technologies. For future research, empirical research may address to integrate all four determinant factors into agricultural technology adoption model. Future review may consider to use more structurally methods such as systematic review and meta-analysis with involving relatively complex statistical procedures. In addition, to conduct such an adoption review, special focus may be placed on specific type of agricultural technologies/innovations.

CONTRIBUTION STATEMENT

Suprehatin is the main contributor in this paper.
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