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Li, Fenni; Zhang, Junbiao; Ma, Chunbo

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# Does family life cycle influence farm households' adoption decisions concerning sustainable agricultural technology?

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# Does family life cycle influence farm households' adoption decisions concerning sustainable agricultural technology?

Fenni Li<sup>a,b</sup>, Junbiao Zhang<sup>a,b</sup> and Chunbo Ma<sup>c</sup>

<sup>a</sup>College of Economics & Management, Huazhong Agricultural University, Wuhan, China; <sup>b</sup>Hubei Rural Development Research Center, Huazhong Agricultural University, Wuhan, Hubei, China; <sup>c</sup>School of Agriculture and Environment, University of Western Australia, Perth, Australia

#### ABSTRACT

The literature examining the role played by family life cycle in farm households' decisions to adopt sustainable agricultural technology (SAT) remains scant. To bridge this gap, we evaluate the impact of family life cycle on farm households' adoption of SATs by using multivariate probit regression analyses of survey data from 902 farm households in Hubei Province, China. The results show that most farm households belong to the middle stages of the family life cycle. Straw returning is the most frequently adopted SAT among farm households. Farm households' SAT adoption decisions are closely related to family life cycle. SAT adoption by farm households differs at each family life cycle stage. Based on this finding, when stimulating SAT adoption, the government should consider the different capital endowments and needs of farm households at different family life cycle stages as well as conduct differential and targeted technology promotion measures.

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Family life cycle; sustainable agricultural technologies; adoption decision; multivariate probit model

# 1. Introduction

Sustainable agricultural technology (SAT), a production technology that improves agricultural productivity and rural livelihood and, more critically, conserves agricultural resources and maintains harmony between nature and the economy (Khonje, Julius, Petros, Hirpa, & Alene, 2018; Zeng, Zhang, He, & Chen, 2019), has been promoted by the efforts of numerous national and international organizations. However, several studies have found that the adoption rate of SATs is relatively low in China, Ethiopia, Tanzania, and other developing countries or regions (Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013; Teklewold, Kassie, & Shiferaw, 2013; Zeng, Zhang, He, & Chen, 2019).

Bourdieu (1986) stated that only with a minimum level of capital endowment can individuals make behavioural decisions. Therefore, to determine the factors influencing SAT adoption and to stimulate farm households' adoption of SATs, scholars have mainly focused on the personal characteristics of the household head or the characteristics of the farm household (Li, Chen, Tang, & Feng, 2020), such as educational attainment (Khonje, Julius, Petros, Hirpa, & Alene, 2018), risk preference (Andres, Pennings, & Dianne,

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CONTACT Junbiao Zhang 🖾 zhangjb513@126.com 🖃 College of Economics and Management, Huazhong Agricultural University, Room 301, Crop Sciences Building, 1st Shizishan Street, Wuhan, Hubei, China

2016), household size (Teklewold, Kassie, & Shiferaw, 2013), farm size and number of livestock owned (Kassie, Teklewold, Jaleta, Paswel, & Olaf, 2015), number of labourers (Zeng, Zhang, He, & Chen, 2019), and household income (Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013), without taking into account the dynamic perspective of the family life cycle. In fact, considering the family life cycle when observing SAT adoption is of great significance for understanding Chinese farm households' behavioural logic (Chang, Li, Xie, & Zhao, 2020; Li, Chen, Tang, & Feng, 2020). First, China has a strong sense of "family orientation" (Li, Chen, Tang, & Feng, 2020). The production and resource allocation activities of Chinese farm households are carried out in a way that is centered on the family (Liang, Lin, & Zhang, 2015). Furthermore, based on the analytical framework of "capital endowments  $\rightarrow$  production technology behaviour choice", farm households' technology adoption decisions are deeply affected by their capital endowments (Li, Chen, Tang, & Feng, 2020; Xu et al., 2020). There is a close association between the capital endowments and the family life cycle of farm households (Wang & Wu, 2017). Capital endowments accumulate as the family life cycle develops (Xu et al., 2020). Hence, analyzing farm households' SAT adoption in the context of family life cycle may be beneficial to the development of the analytical framework from a pattern of "capital endowments  $\rightarrow$  production technology behaviour choice" to one of "family life cycle  $\rightarrow$  capital endowments  $\rightarrow$  production technology behaviour choice" and to the enrichment of the literature on farm households' technology adoption behaviour. Second, family life cycle is a compound concept that includes several household characteristics, such as labour resources and capital accumulation (Chao & Wan, 2016; Su, Feng, & Zhu, 2020), and it can more comprehensively reflect capital endowments at different stages (Su, Feng, & Zhu, 2020). In other words, farm households at different family life cycle stages have different levels of capital endowment and different constraints in terms of household burden, ability to resist risk, capital accumulation, production needs, etc. (Leinbach & Smith, 1994; Li, Chen, Tang, & Feng, 2020; Neulinger & Rado, 2018; Perz & Walker, 2002; Xu et al., 2020), which results in differentiated agricultural production and management decisions by farm households related to their current family life cycle characteristics (Chang, Li, Xie, & Zhao, 2020; He, Zhang, & Tian, 2013; Perz & Walker, 2002; Sherbinin, Vanwey, Mcsweeney, Aggarwal, & Walker, 2008). Thus, an exploration from the family life cycle perspective can better explain differences in farm households' adoption decisions concerning technology (Su, Feng, & Zhu, 2020).

In fact, many researchers have found that family life cycle is significantly correlated with personal or household behaviour. For example, Zinda and Zhang (2017) argued that the livelihood strategy formulation of farm households is largely affected by their family life cycle. A study by Amirtha and Sivakumar (2018) concerning India found that family life cycle influences women to engage in e-shopping. Liang, Lin, and Zhang (2015) pointed out that family life cycle produces a marked effect on farm scale choice in southern China. Leinbach and Smith (1994) stated that the off-farm employment participation of farm households is closely related to their family life cycle. However, to the best of our knowledge, no previous studies have attached importance to the role played by family life cycle in farm households' SAT adoption in China. Similarly, family life cycle has been applied less frequently in the field of farm households' technology adoption behaviour. Therefore, we include the consideration of family life cycle in the analysis of SAT adoption, attempting to fill the gap in the literature concerning the impact of family

life cycle on farm households' agricultural production behaviour. Furthermore, the literature on SAT adoption has concentrated mainly on the adoption of a particular sustainable agricultural technology by farm households. In fact, SAT is a technology package consisting of various subtechnologies. It is possible for farm households to adopt a mix of SATs for agricultural production processes (Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013; Li, Zhang, & He, 2019). Therefore, it is necessary to investigate multiple SATs and construct an accurate model to explore farm households' adoption decisions. Additionally, prior studies on SAT adoption have mostly explained the reasons why farm households adopt or do not adopt SATs by way of one attribute of SATs, ignoring the fact that SATs have multiple attributes pertaining to capital, labour, and production risk. For example, Sall, Norman, and Featherstone (2000) merely pointed out that improved seed technology is capital intensive. Luo, Qin, Wang, and Wang (2016) simply identified soil testing and fertilizer recommendations as a labour-intensive technology. Zeng, Zhang, He, and Chen (2019) merely recognized that no-/mini-tillage technology would increase output risk. Thus, these conclusions are not only likely to fail to illustrate the reasons why farm households differ in their adoption of and need for SATs but are also insufficient as guides to farm households' sustainable agricultural production practices.

Based on this foundation, using the multivariate probit model and survey data from 902 farm households in Hubei Province, China, and taking four SATs as examples, we attempt to accomplish the following goals: (1) to reveal the importance of family life cycle on farm households' SAT adoption decisions in order to expand the scope of application of the concept of family life cycle and to enrich the literature concerning farm households' technology adoption behaviour, and (2) to shed light on the heterogeneity of SAT adoption by farm households at different family life cycle stages in order to provide a basis for accurately understanding the main extension agents of SATs with different attributes, thus improving the pertinence of SAT extension measures and realizing the optimization of agricultural technology popularization strategies.

The structure is as follows: Section 2 presents family life cycle divisions in rural China and research hypothesis. Sections 3 introduces the data, variable and method. Section 4 reveals the estimation results. Section 5 reports the conclusion and relevant policy implication.

# 2. Concept definition and research hypothesis

#### 2.1. Family life cycle divisions in rural China

Family life cycle describes the process of marriage, childbirth, children leaving home, and death within a household (Xu et al., 2020). Sorokin, Zimmermann, and Galpin (1931) first proposed this concept and divided family life cycle into four stages. Many scholars have amended and perfected family life cycle theory in accordance with the reality of the situation within nations and classified family life cycle into seven (Lansing & Kish, 1957), eight (Duvall, 1971), nine (Wells & Gubar, 1966), and 13 stages (Murphy & Staples, 1979). Glick (1947) introduced a division of family life cycle into six stages: formation, expansion, stabilization, contraction, empty nest, and disintegration, a model which is recognized as the classical family life cycle theory and is commonly used internationally (Xu et al., 2020).

124 👄 F. LI ET AL.

However, there are differences in family culture and lifestyle between rural China and other countries (He, Zhang, & Tian, 2013; Xu et al., 2020). Specifically, due to a lack of independent income, newlyweds in rural China usually live together with their parents for a period of time rather than living alone (Li, 2005; Xu et al., 2020). Thus, the establishment of a new household in rural China begins with financial separation rather than marriage (Li, Chen, Tang, & Feng, 2020; Liang, Lin, & Zhang, 2015). Second, considering birth control policy in China, most farm households have only one child in the household rather than the large number of children typical in Western households (Ye, Cai, Chen, & Xia, 2019). Third, considering the deep influence of Confucian culture in contrast to individualistic family relationships in Western societies, Chinese farm households support their elderly parents and live with them, forming multigenerational households (He, Zhang, & Tian, 2013; Li, Chen, Tang, & Feng, 2020). This structure indicates that households containing elderly parents as the main figures gradually vanish and are integrated into a family life cycle stage dominated by their children (Liang, Lin, & Zhang, 2015; Xu et al., 2020). In general, the concept of family life cycle in rural China is so complicated (Liang, Lin, & Zhang, 2015) that classical family life cycle theory is insufficient to explain the issue in China.

Under these circumstances, Chinese scholars have adjusted their classification of family life cycle to suit the reality of the situation within rural China. For instance, based on the number and ages of children, Li (2005) divided the family life cycle into four stages, including beginning families, maturing families, matured families, and aging families. Based on the ages of children and the elderly, some scholars have classified the family life cycle into five stages (Liang, Lin, & Zhang, 2015; Peng & Wu, 2017), such as a classification that employs the stages of "young couple family, growing nuclear family, mature nuclear family, extended family, and empty nest family" (Liang, Lin, & Zhang, 2015) or a classification using stages of "start-up, growth, maturity, expansion, and decline" (Peng & Wu, 2017). Others have extended this classification and divided the family life cycle into six stages based on household size and demographic structure (Chao & Wan, 2016; He, Zhang, & Tian, 2013; Li, Chen, Tang, & Feng, 2020; Xu et al., 2020), such as a classification that employs the stages of "couple nuclear family, growing nuclear family, mature nuclear family, extended family I, extended family II, and shrinking family" (Li, Chen, Tang, & Feng, 2020), a classification using the stages of "starting period, rearing period, burden period, stable period, maintenance period, and empty nest period" (Xu et al., 2020), a classification that employs the stages of "couple nuclear family, standard nuclear family, extended nuclear family, lineal family, extended lineal family, and shrinking family" (He, Zhang, & Tian, 2013), or a classification using the stages of "bachelorhood, newlywed, full nest 1, full nest 2, full nest 3, and empty nest" (Chao & Wan, 2016). Furthermore, Zhu, Yang, and Rao (2017) constructed a model of family life cycle employing seven stages: single family, newlywed family, growing nuclear family, mature nuclear family, extended family, empty nest family, and family living alone.

As mentioned above, different studies employ divergent approaches to the classification of family life cycle. Derrick and Lehfeld (1980) stated that the division of family life cycle should be determined by research purpose and data. Thus, referring to the literature above (Chang, Li, Xie, & Zhao, 2020; Xu et al., 2020), we divide the family life cycle in rural China into six stages. Specifically, if farm households are married but have no children, they are considered to belong to the starting period. If farm households have

Family life cycle	Division
Starting period	Young and childless couples
Rearing period	Children or grandchildren born, the youngest children or grandchildren are under the age of 16, and there are household members between the ages of 17 and 64
Burden period	Children or grandchildren born, the youngest children or grandchildren are under the age of 16, and there are household members over the age of 65
Stable period	All household members are between the ages of 17 and 64
Maintenance period	All children or grandchildren are over the age of 16 and there are household members over the age of 65
Empty nest period	All household members are over the age of 65

Table 1. Family life cycle divisions in rural China.

children or grandchildren, the youngest children or grandchildren are under 16 years old, and other members of the family are between the ages of 17 and 64, then they are considered to belong to the rearing period. If farm households have children or grand-children, the youngest children or grandchildren are under 16 years old, and the household contain members over the age of 65, then they are considered to belong to the farm households are considered to belong to the stable period. If the household contain members over the age of 65 and all children or grandchildren are over the age of 16, then the farm households are considered to belong to the stable period. If the household contain members over the age of 65 and all children or grandchildren are over the age of 16, then the farm households are considered to belong to the maintenance period. If all household are over the age of 65, then the farm households are considered to belong to the maintenance period. If all household members in the household are over the age of 65, then the farm households are considered to belong to the age of 65, then the farm households are considered to belong to the maintenance period. If all household members in the household are over the age of 65, then the farm households are considered to belong to the empty nest period. The details are shown in Table 1.

### 2.2. Research hypothesis

Many scholars have found that the labour supply, income level, and risk aversion level of farm households all change with the continuous evolution of the household's family life cycle (Liang, Lin, & Zhang, 2015; Xu et al., 2020). For example, Lansing and Kish (1957) argued that there is an inverted U-shaped correlation between the family life cycle of farm households and their income level. A study by Su, Feng, and Zhu (2020) showed that farm households' risk aversion level is closely related to their family life cycle. Zhu, Yang, and Rao (2017) and Xu et al. (2020) noted that the family life cycle of farm households affects their labour supply. The above factors have an important influence on SAT adoption by farm households. Based on this fact, the hypothesis of this study is as follows.

First, there is a close relationship between family life cycle and farm households' income level (Brown, Venkatesh, & Viswanath, 2005; Zhu, Yang, & Rao, 2017). Household income level differs over different stages of the family life cycle (Li, 2005; Zhu, Yang, & Rao, 2017). Additionally, scholars have reached consensus that household income level exerts a positive impact on farm households' SAT adoption. That is, the higher the income level is, the fewer farm households are limited by financial conditions in the adoption of SATs (Christine & David, 1982; Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013; Kassie, Teklewold, Jaleta, Paswel, & Olaf, 2015; Teklewold, Kassie, & Shiferaw, 2013). Therefore, family life cycle may influence the SAT adoption decisions of farm households by affecting household income level. Specifically, for farm households in the early family life cycle stage, capital accumulation is limited due to recent separation from the original households and the

126 👄 F. LI ET AL.

formation of new households (Zhu, Yang, & Rao, 2017), and thus, such households are constrained in terms of capital and less motivated to adopt SATs. When the family life cycle of farm households develops to the stage that is characterized by childbearing and paternal aging, the presence of elderly individuals and minors in the household increases support and maintenance burden and reduces the financial stability and income level of farm households (Amirtha & Sivakumar, 2018; Amirtha, Sivakumar, & Hwang, 2020; Li, 2005; Li, Chen, Tang, & Feng, 2020; Su, Feng, & Zhu, 2020; Walker, Perz, Caldas, & Silva, 2002; Zhu, Yang, & Rao, 2017); as a result, farm households are likely to face financial constraints in SAT adoption. As farm households' family life cycle reaches the stage where all household members are adults, off-farm work by adult children not only contributes to a high household income level (Amirtha & Sivakumar, 2018; Li, 2005) but also provides a good financial base, thereby granting farm households abundant funds for SAT adoption. When farm households reach a later family life cycle stage, although the physical condition and work capacity of their members deteriorate, long-term capital accumulation allows such households to maintain financial stability; as a result, these farm households are less limited by financial conditions in SAT adoption.

Second, family life cycle may lead to changes in the number of labourers available for farm production in the household (Su, Feng, & Zhu, 2020; Xu et al., 2020; Zhu, Yang, & Rao, 2017). Farm households have different numbers of labourers at different family life cycle stages (Li, 2005; Zhu, Yang, & Rao, 2017). Additionally, positive impacts by the number of labourers on farm households' SAT adoption have been found by most researchers (Feder, Just, & Zilberman, 1985; Supaporn, Kobayashi, & Supawadee, 2013; Thangata & Alavalapati, 2003). That is, the greater the number of labourers among farm households, the greater the availability of labour resources to assist in technology application (Ofuoku, Egho, & Enujeke, 2008) and the higher the likelihood of farm households adopting SATs. Thus, family life cycle may influence farm households' decision to adopt SATs by affecting the supply of labourers who engage in sustainable agricultural production (Su, Feng, & Zhu, 2020). Specifically, for farm households in the early family life cycle stage, the labour force at this stage is adequate, young, and able-bodied (Li, 2005; Peng & Wu, 2017), and therefore, such households have abundant labour resources to assist in SAT adoption. When the family life cycle of farm households develops into the middle stage, household merging or expansion of household size allows for greater allocation of labour resources to farm production (Amirtha & Sivakumar, 2018; Li, 2005; Li, Chen, Tang, & Feng, 2020). Additionally, growing children could add to the household labour pool (Barbieri, Bilsborrow, & Pan, 2005; Leinbach & Smith, 1994; Li, 2005; Perz, Walker, & Caldas, 2006; Sherbinin, Vanwey, Mcsweeney, Aggarwal, & Walker, 2008; Su, Feng, & Zhu, 2020; Zinda & Zhang, 2017), thus enabling farm households to have adequate labour resources (Walker, Perz, Caldas, & Silva, 2002) and meet the labour demand for SAT adoption. As the family life cycle of farm households evolves to the stage where all household members are adults, off-farm work by members may affect the number of labourers allocated to agricultural production (Perz, Walker, & Caldas, 2006; Su, Feng, & Zhu, 2020; Zinda & Zhang, 2017), thus influencing the labour resources available for technology adoption and the likelihood of farm households adopting SATs (Kassie, Teklewold, Jaleta, Paswel, & Olaf, 2015). When the family life cycle of farm households enters the later stage during which all household members are elderly individuals, reduction in household size and the gradual

decline of members' work capacity render the labour resources allocated to farm production insufficient (Chang, Li, Xie, & Zhao, 2020; Peng & Wu, 2017; Su, Feng, & Zhu, 2020), which affects the SAT adoption by these households.

Finally, farm households' risk aversion level is closely related to their family life cycle (Su, Feng, & Zhu, 2020). Farm households have different risk aversion levels at different family life cycle stages (García & Gruat, 2003; Su, Feng, & Zhu, 2020), and farm households' technology adoption decisions are strongly influenced by risk aversion level (Andres, Pennings, & Dianne, 2016; Kassie, Teklewold, Jaleta, Paswel, & Olaf, 2015). According to the stochastic production function proposed by Just and Pope (1978), farm households with high risk aversion levels are more cautious (Rogers, 1983) and conservative in making adoption decisions concerning new agricultural technologies (Luo, Lin, & Qiu, 2021), preferring risk-mitigating production elements and technologies (Hou, Qiu, Bai, & Xu, 2014; Su, Feng, & Zhu, 2020). Therefore, family life cycle may influence the SAT adoption decisions of farm households by affecting risk aversion level. Specifically, in the early family life cycle stage, the inexperience of farm households dispose them toward high risk aversion (Zhang, He, & Yang, 2020), leading to a cautious adoption of SATs and other new technologies. When the family life cycle of farm households enters the stage in which there are minors in the household, the presence of those minors would increase the risk aversion level (Amirtha, Sivakumar, & Hwang, 2020; Yi & Zhu, 2017) and result in a conservative adoption decision concerning SATs and other new technologies by farm households. The cause of this risk aversion is that minor is an unproductive, socially dependent population (Leinbach & Smith, 1994) that does not contribute to the labour supply and provides negative savings. When the family life cycle of farm households enters the middle stage, the acquisition of experience makes them less risk averse (Walker, Perz, Caldas, & Silva, 2002; Zhang, He, & Yang, 2020). Additionally, growing children, youth, and middle-aged members can contribute to the household (Barbieri, Bilsborrow, & Pan, 2005; Leinbach & Smith, 1994; Li, 2005; Perz, Walker, & Caldas, 2006; Sherbinin, Vanwey, Mcsweeney, Aggarwal, & Walker, 2008; Su, Feng, & Zhu, 2020; Zinda & Zhang, 2017), which, to a certain extent, enhances farm households' ability to obtain income (Wang & Deng, 2015) and alleviates risk aversion level (Perz, Walker, & Caldas, 2006; Walker, Perz, Caldas, & Silva., 2002), thereby increasing the probability of SAT adoption. As farm households reach a later family life cycle stage in which all household members are elderly individuals, the risk aversion levels of farm households tend to increase (Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013; Kassie, Teklewold, Jaleta, Paswel, & Olaf, 2015; Riley & Chow, 1992) due to the conservative value orientation of the older population (Simon & Khaled, 2015), which ultimately leads them to be more cautious in adopting SATs.

Furthermore, farm households at different family life cycle stages are likely to make different choices in the context of SAT adoption. Specifically, farm households in the starting period are young couples without children. Farm households at this stage have just separated from the original household. They usually inherit some property from their parents (Sherbinin, Vanwey, Mcsweeney, Aggarwal, & Walker, 2008), but capital accumulation is still insufficient (Lin, Zhang, & Lin, 2011). The labour resources owned by farm households in the starting period are adequate (Peng & Wu, 2017). The labour force at this stage is also young, able-bodied, and has abundant physical strength for

engaging in agricultural production (Li, 2005). Additionally, farm households in the starting period tend to have relatively high risk aversion levels (Zhang, He, & Yang, 2020) and weak risk resistance (Zhu, Yang, & Rao, 2017) because of their youth and inexperience. Thus, farm households in the starting period face relatively strong capital constraints, have relatively high risk aversion levels and possess sufficient labour endowments; therefore, they are more likely to adopt capital-stabilizing SATs.

Farm households in the rearing period are responsible for raising and taking care of dependent children and grandchildren under 16 years of age, which not only increases the financial burden and financial instability of farm households (Amirtha & Sivakumar, 2018; Li, 2005; Li, Chen, Tang, & Feng, 2020; Liang, Lin, & Zhang, 2015; Su, Feng, & Zhu, 2020; Wang & Wu, 2017; Ye, Cai, Chen, & Xia, 2019; Zhu, Yang, & Rao, 2017) but also increases their risk aversion level (Yi & Zhu, 2017). In addition, the work capacity and quality of labourers owned by farm households in the rearing period are high (Li, 2005; Lin, Zhang, & Lin, 2011). Consequently, for farm households in the rearing period, risk aversion levels are relatively high, labour constraints are relatively weak, and capital constraints are relatively strong; thus, they tend to adopt SATs with capital-stabilizing characteristics.

Farm households in the burden period have elderly individuals and minors in the household (Xu et al., 2020). The dual task of teenager parenting and eldercare not only makes them relatively risk averse (Lin, Zhang, & Lin, 2011; Su, Feng, & Zhu, 2020) but also increases financial burden (Smith, 1994; Wang & Wu, 2017; Zhu, Yang, & Rao, 2017; Ye, Cai, Chen, & Xia, 2019; Li, Chen, Tang, & Feng, 2020; Li, 2005; Liang, Lin, & Zhang, 2015). Additionally, the need to support and take care of elderly individuals and minors reduces farm households' propensity to leave the household to work (Li, Chen, Tang, & Feng, 2020; Liang, Lin, & Zhang, 2015; Lin, Zhang, & Lin, 2011; Su, Feng, & Zhu, 2020; Wang & Wu, 2017; Xu et al., 2020), resulting in an increase in the number of labourers allocated to agricultural production (Su, Feng, & Zhu, 2020). Thus, for farm households in the burden period, labour constraints are relatively weak, capital constraints are relatively strong, and risk aversion levels are relatively high; therefore, they are more likely to adopt capital-stabilizing and risk-mitigating SATs.

The stable period is a period when financial burden and household size are in a relatively steady state (Wang & Wu, 2017). Farm households at this stage have some capital (Zhu, Yang, & Rao, 2017) and do not have the pressure of supporting elderly individuals and minors (Li, Chen, Tang, & Feng, 2020); as a result, financial burden is relatively light (Wang & Wu, 2017; Zhu, Yang, & Rao, 2017) and the risk aversion level is relatively low (Su, Feng, & Zhu, 2020). Farm households in the stable period have abundant and high-quality labourers (Li, 2005), but off-farm work by young and middle-aged labourers may affect the agricultural labour supply (Su, Feng, & Zhu, 2020), thereby increasing the likelihood of farm households adopting labour-saving SATs. In addition, the income from off-farm work by young and able-bodied members could contribute to household agricultural production activities (Peng & Wu, 2017; Walker, Perz, Caldas, & Silva, 2002; Zhu, Yang, & Rao, 2017; Zinda & Zhang, 2017), thus decreasing the limits of the financial conditions necessary for technology adoption on farm households and increasing the probability of the adoption of capital-intensive SATs. Hence, farm households in the stable period face relatively weak capital constraints, possess abundant labour resources and have relatively low risk aversion levels; therefore, they are more likely to adopt SATs.

Farm households in the maintenance period need to take care of members over the age of 65, while the overall financial pressure of farm households is light due to a long period of capital accumulation (Ye, Cai, Chen, & Xia, 2019). For farm households at this stage, agricultural labourers are abundant (Ye, Cai, Chen, & Xia, 2019), while the work capacity of labourers tends to deteriorate (Wang & Wu, 2017). Additionally, the tendency of young and able-bodied members to leave the household to work directly reduces the agricultural labour supply (Su, Feng, & Zhu, 2020) and thus increases the likelihood of farm households adopting labour-saving SATs. Alternately, income from off-farm work by young and able-bodied members could support the family (Ye, Cai, Chen, & Xia, 2019; Zhu, Yang, & Rao, 2017), thereby increasing the risk resistance of farm households (Zhu, Yang, & Rao, 2017). Thus, for farm households in the maintenance period, capital constraints are relatively weak, risk aversion levels are relatively low, and labour constraints are relatively strong; therefore, they have a high likelihood of adopting labour-saving SATs.

Farm households in the empty nest period are characterized by all household members being over 65 years old. As farm households at this stage are at the extreme end of the aging process, risk resistance is relatively weak, risk aversion level is relatively high (Su, Feng, & Zhu, 2020), and the physical condition and work capacity of labourers tend to deteriorate (Chang, Li, Xie, & Zhao, 2020; Ye, Cai, Chen, & Xia, 2019; Zhu, Yang, & Rao, 2017). In addition, because of a long period of capital accumulation, the income level of such households is relatively stable (Amirtha & Sivakumar, 2018; Li, 2005), and material capital is relatively abundant (Peng & Wu, 2017). As a consequence, farm households in the empty nest period face relatively weak capital constraints and relatively strong labour constraints and have relatively high risk aversion levels; thus, they are more likely to adopt SATs with labour-saving and risk-mitigating characteristics.

Therefore, we propose the following hypothesis: Family life cycle affects farm households' adoption decisions concerning SAT and farm households at different family life cycle stages differ in their SAT adoption decisions.

#### 3. Data and methodology

#### 3.1. Data collection

The data used for this study were taken from a survey of farm households conducted in Tianmen city, Huanggang city, Suizhou city, Wuhan city, and Jingzhou city in Hubei Province, China, between July and August 2017. Located along the middle and lower reaches of the Yangtze River, Hubei Province is an important agricultural province and a famous commodity grain base in China. Thus, it is representative to take Hubei Province as an example. These regions were selected for the following reasons. First, their shares of GDP in 2017 were taken into consideration. Among the 17 cities in Hubei Province, Wuhan city ranked first. Huanggang city and Jingzhou city ranked fourth and fifth, respectively. Suizhou city and Tianmen city ranked 11th and 16th, respectively. Second, the terrain was considered. Huanggang city and Suizhou city lie on hilly landforms. Tianmen city, Wuhan city, and Jingzhou city lie on plain landforms. Therefore, these five regions represent the basic topographic features of Hubei Province. Third, agricultural production conditions were accounted for. These five regions are important 130 🕞 F. LI ET AL.

high-quality grain bases in China and are key areas for governmental promotion of sustainable agriculture. Thus, it is representative to analyze farm households' SAT adoption behaviour in these regions.

Both the random sampling strategy and stratified sampling strategy were used in this survey. First, three or four towns were randomly selected from the sampled city. Then, two or three villages were chosen from the towns in the same way. Finally, 10 surveyed farm households were selected from the sampled villages. The survey was conducted on the basis of one-to-one interviews. The survey team consisted of doctoral students and postgraduates who were experienced in conducting rural surveys and had received professional training before the formal survey. The questionnaire collected details about the personal characteristics of the household head, household characteristics, agricultural production status, perception toward SATs, and adoption willingness and behaviour. After excluding invalid questionnaires, 902 valid questionnaires were obtained.

# 3.2. Variables and descriptive statistics

# 3.2.1. Family life cycle

As reported in the previous section, the family life cycle in rural China is divided into six stages, namely, starting period, rearing period, burden period, stable period, maintenance period, and empty nest period. The distributions of farm households at different family life cycle stages are shown in Table 2. Most farm households belonged to the rearing period, accounting for 35.6% of the total sample. The next most numerous were households in the stable period (25.2%), burden period (19.3%), and maintenance period (13.2%). Few farm households belonged to the starting period (0.4%) and empty nest period (6.3%). This finding is similar to the observations of most Chinese studies, such as Xu et al. (2020), Wang and Wu (2017), and Chang, Li, Xie, and Zhao (2020).

# 3.2.2. SATs

According to the list of SATs in Lee's (2005) work, combined with different agricultural production processes and survey data, we take four SATs as examples. (1) Water-saving irrigation technology (including lined canals and drip irrigation systems) is beneficial in reducing irrigation water use (Huang, Wang, & Li, 2017), labour demand (Kuscu, 2013) and drought losses in agricultural production (He, Hu, & Lu, 2018) as well as in improving the productivity of water (Huang, Wang, & Li, 2017) and crop yield (Schulz, Makary, Hubert, Hartung, & Donath, 2015). However, the application of this technology involves a purchase of supporting facilities, thereby increasing the capital investments of farm households (Huang, Wang, & Li, 2017). Thus, water-saving irrigation technology is risk-mitigating, capital intensive, and labour-saving. (2) Commercial organic fertilizer technology is conducive to improving soil fertility. However, it is characterized by large volume, inconvenient application processes, and high costs (Hu et al., 2020), which indicates that it increases the production costs and labour demand of farm households (Li, Zhang, & He, 2019). Therefore, commercial organic fertilizer technology is risk-mitigating, capital intensive, and labour intensive. (3) Straw returning technology is of great significance in achieving high yields and soil fertility. However, the benefits of straw returning require a certain time to take effect. Use of this technology also involves mechanical crushing, which increases the capital investments of farm

Variables		Definitions and assignments	Mean	SD
Sustainable agricultural technologies	Water-saving irrigation Commercial organic fertilizer	1 if water-saving irrigation is adopted; 0 otherwise 1 if commercial organic fertilizer is adopted; 0 otherwise	0.366 0.443	0.482 0.497
	Straw returning	1 if straw returning is adopted; 0 otherwise	0.759	0.427
	Comprehensive utilization of livestock manure	1 if comprehensive utilization of livestock manure is adopted; 0 otherwise	0.612	0.487
Family life cycle	Starting period	1 if farm household belongs to the starting period; 0 otherwise	0.004	0.066
	Rearing period	1 if farm household belongs to the rearing period; 0 otherwise	0.356	0.479
	Burden period	1 if farm household belongs to the burden period; 0 otherwise	0.193	0.395
	Stable period	1 if farm household belongs to the stable period; 0 otherwise	0.252	0.434
	Maintenance period	1 if farm household belongs to the maintenance period: 0 otherwise	0.132	0.338
	Empty nest period	1 if farm household belongs to the empty nest period: 0 otherwise	0.063	0.243
Control	Gender	1 if household head is male; 0 otherwise	0.875	0.331
variables	Age	Age of household head (year)	58.340	10.044
	Education level	Education level of household head (year)	6.719	3.309
	Risk averse (with risk preference as the reference)	1 if household head is risk averse; 0 otherwise	0.543	0.498
	Risk neutral	1 if household head is risk neutral; 0 otherwise	0.252	0.434
	Household income	Annual household income (10,000 yuan)	6.601	4.945
	Number of labourers	Number of labourers in the household	3.257	1.402
	Off-farm work	1 if household member participates in off-farm work; 0 otherwise	0.823	0.382
	Land acreage	Land acreage (mu)	8.221	8.575
	Number of livestock owned	Cow×1+ sheep×0.8+ pig×0.3+ chicken×0.2 + duck×0.2+ goose×0.2	33.278	457.722
	Adoption benefit	1 if household head perceives that the products of sustainable agricultural production could be sold at higher prices	0.262	0.440
	Adoption cost	1 if household head perceives the cost for SAT adoption to be high	0.654	0.476
	Village terrain	1 if farm household resides in hilly village; 0 otherwise	0.394	0.489
	Distance to market or town	Distance to market or town (km)	4.593	3.695
	Regional dummy variables (with Tianmen city as the	1 if farm household resides in Huanggang city; 0 otherwise	0.174	0.379
	reference)	1 if farm household resides in Wuhan city; 0 otherwise	0.169	0.374
		1 if farm household resides in Jingzhou city; 0 otherwise	0.201	0.400
		1 if farm household resides in Suizhou city; 0 otherwise	0.229	0.421

Table 2. Variable definitions and summary statistics.

households (Zheng, Wang, & Ying, 2018). Additionally, if the straw is not crushed completely, the possibility of disease and insect damage increases, which is likely to result in yield loss and a lower income (Zheng, Wang, & Ying, 2018). Thus, straw returning technology does not mitigate risk and exhibits capital-intensive and labour-saving characteristics. (4) Comprehensive utilization of livestock manure technology enables the reduction of environmental pollution, enhancement of land productivity, and improvement of resource utilization efficiency. The application of this technology generally does not require additional capital from farm households, but manure is difficult to transport and requires time, labour and effort from farm households

(Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013). Therefore, comprehensive utilization of livestock manure technology is risk-mitigating, capital-stabilizing, and labour intensive.

Table 2 reports farm households' adoption of SATs. Straw returning was the most frequently adopted SAT among farm households, with an adoption rate of 75.9%. The next most frequently adopted technology were the comprehensive utilization of livestock manure (61.2%) and commercial organic fertilizer (44.3%). Water-saving irrigation was a technology rarely adopted by farm households, with an adoption rate of 36.6%.

# 3.2.3. Control variables

Referring to the studies by Kassie, Jaleta, Shiferaw, Mmbando, and Mekuria (2013), Kassie, Teklewold, Jaleta, Paswel, and Olaf (2015), and He, Hu, and Lu (2018), we include gender, age, education level, risk aversion level, household income, number of labourers, off-farm work, land acreage, number of livestock owned, adoption benefit, adoption cost, village terrain, distance to market or town, and regional dummy variables as control variables. Descriptions of all variables are presented in Table 2.

# 3.3. Model selection

Farm households' SAT adoption decisions constitute a binomial variable. It is possible for farm households to adopt various SATs at the same time. Therefore, referring to the studies by Zeng, Zhang, He, and Chen (2019), Teklewold, Kassie, and Shiferaw (2013), and Li, Zhang, and He (2019), we construct a multivariate probit model. The general expression of the model is as follows:

$$Y_{j}^{*} = \beta_{j}X + \mu_{j}$$

$$Y_{j} = \{ \begin{array}{ccc} 1, & if & Y_{j}^{*} > 0\\ 0, & if & Y_{j}^{*} \le 0 \end{array}$$
(1)

Where *j* represents the four SATs.  $Y_j^*$  represents an unobservable latent variable.  $Y_j$  is the final result variable. If  $Y_j^*>0$ , then  $Y_j = 1$ , indicating that farm households have adopted SATs. *X* represents the explanatory variable, such as family life cycle stage.  $B_j$  is the estimation coefficient.  $\mu$  is the random disturbance term.

# 4. Empirical results and discussions

# 4.1. The impact of family life cycle on farm households' SAT adoption decisions

Table 3 shows the regression results for the impact of family life cycle on farm households' SAT adoption decisions. Regression 1 shows the results for control variables. Regression 2 reports the results using farm households in the empty nest period as the reference. Regression 3 shows the results using farm households in the rearing period as the reference. The Log likelihood and Wald chi<sup>2</sup> gradually increase with the inclusion of variables, indicating that the explanatory power of the regression model gradually increases. Due to the small sample size for farm households in the starting period,

		eg.	ression 1			Reg	ression 2			Regr	ession 3	
		(amono)		Comprehensive	11/24-22	l'eiene de la composition de		Comprehensive	141-4-2-2	lein meno		Comprehensive
	saving	organic	Straw	livestock	saving	organic	Straw	livestock	saving	organic	Straw	livestock
Variables	irrigation	fertilizer	returning	manure	irrigation	fertilizer	returning	manure	irrigation	fertilizer	returning	manure
Family life					-0.469*	-0.066	0.408	0.529*				
cycle = rearing					(0.222)	(0.212)	(0.247)	(0.233)				
periou Eamily life						01010	0.075	0 0 U V ***	2000	0112	*730.0	*0700
ranny me airdon					7 <del>44</del> 70-	(210.0	C/0.0	100.0	10100	0.140	(015.0)	(0110)
cycle = purgen period					(007.0)	(117.0)	(662.0)	(0,242,0)	(001.0)	(0.129)	(cc1.0)	(0.149)
Family life					0.546*	0.605**	0.849**	0.909***	1.022***	0.670***	0.424*	0.398**
cycle = stable					(0.231)	(0.219)	(0.272)	(0.245)	(0.149)	(0.128)	(0.179)	(0.150)
period												
Family life cvcle = maintenance					0.622**	-0.219	1.244***	-1.477***	1.102***	-0.155	0.804***	-1.983***
period					(0.235)	(0.222)	(0.273)	(0.302)	(0.171)	(0.155)	(0.203)	(0.242)
Family life									0.532*	0.059	-0.550*	-0.431
cycle = empty nest									(0.230)	(0.219)	(0.258)	(0.242)
period												
Gender	-0.082	-0.099	-0.021	-0.072	-0.062	-0.087	0.066	0.015	-0.062	-0.087	0.066	0.012
	(0.147)	(0.131)	(0.154)	(0.150)	(0.155)	(0.133)	(0.158)	(0.163)	(0.155)	(0.133)	(0.158)	(0.163)
Age	0.000	0.003	0.001	-0.008	-0.003	0.006	0.001	0.002	-0.004	0.006	0.003	0.002
	(0.005)	(0.005)	(0.006)	(0.005)	(0.006)	(0.005)	(900.0)	(0.006)	(0.006)	(0.005)	(0.006)	(0.006)
Education level	-0.013	-0.013	-0.008	0.002	-0.010	-0.013	-0.009	0.003	-0.010	-0.013	-0.009	0.003
	(0.015)	(0.014)	(0.017)	(0.016)	(0.016)	(0.014)	(0.018)	(0.017)	(0.016)	(0.014)	(0.018)	(0.017)
Risk averse	0.846***	0.062	-0.281*	0.317*	0.771***	0.014	-0.434**	0.423**	0.775***	0.014	-0.438**	0.418**
District Land	(30.13)	0.112)	(0.138)	(0.124)	(0.142)	(211.0)	0.144)	(0.135)	(0.142)	(611.0)	(0.144) 0171	(251.0)
	(0710)		(0.160.0-	(0210)	(0156)	0.043	0,1,0	(0710)	(0.156)	0.043	10.160)	(0110)
Household income	0.045***	0.018*	0.060***	100	0.046***	00120	(//0.1.0) 0.063***	0.007	0.046***	001.0	0.063***	0002
	(0.010)	(0000)	(0.013)	(0.010)	(0.011)	(600.0)	(0.014)	(0.011)	(0.011)	(0000)	(0.014)	(0.011)
Number of labourers	-0.207***	0.066*	-0.106**	0.083*	-0.137***	0.107**	-0.115**	0.081	-0.136***	0.106**	-0.121**	*060.0
	(0.037)	(0.031)	(0:039)	(0.035)	(0.040)	(0.034)	(0.043)	(0.042)	(0.040)	(0.034)	(0.043)	(0.042)
Off-farm work	0.200	0.108	-0.146	-0.022	0.138	0.103	-0.166	0.002	0.126	0.102	-0.149	0.008
	(0.131)	(0.118)	(0.143)	(0.131)	(0.136)	(0.120)	(0.147)	(0.141)	(0.137)	(0.120)	(0.147)	(0.141)
Land acreage	0.019** (0.006)	0.003 (0.005)	0.000 (0.008)	0.002 (0.006)	0.018** (0.006)	0.003 (0.005)	-0.002 (0.008)	0.006 (0.007)	0.018** (0.006)	0.003	-0.002 (0.008)	0.006
												(Continued)

Table 3. The regression results.

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Notes: \* \*\*, and \*\*\* indicate significant at the 10%, 5%, and 1% levels, respectively. Values in the parentheses mean the standard errors. The same below.

referring to the studies by Liang, Lin, and Zhang (2015) and Chang, Li, Xie, and Zhao (2020), we remove these samples and analyze the empirical results based on the remaining five periods.

#### 4.1.1. Family life cycle

Table 3 shows that the rearing period, burden period, stable period, maintenance period, and empty nest period are significant, indicating that family life cycle plays a remarkable role in influencing farm households' SAT adoption decisions.

(1) In Regression 2, the coefficient on the variable "rearing period" is negative and statistically significant at the 10% level in the model of water-saving irrigation. In Regression 2, the coefficient on the variable "rearing period" is positive and statistically significant at the 10% level in the model of comprehensive utilization of livestock manure. These results imply that farm households in the rearing period are inclined to adopt comprehensive utilization of livestock manure technology rather than that of water-saving irrigation technology. The reason for this fact is that farm households in the rearing period have relatively high risk aversion levels and face relatively strong capital constraints. Water-saving irrigation technology is capital intensive. Comprehensive utilization of livestock manure technology of farm households in the rearing period. Therefore, they are more likely to adopt comprehensive utilization of livestock manure technology.

(2) In Regression 2, the coefficient on the variable "burden period" is positive and statistically significant at the 1% level in the model of comprehensive utilization of livestock manure. In Regression 3, the coefficient on the variable "burden period" is negative and statistically significant at the 10% level in the model of straw returning. In Regression 3, the coefficient on the variable "burden period" is positive and statistically significant at the 10% level in the model of straw returning. In Regression 3, the coefficient on the variable "burden period" is positive and statistically significant at the 10% level in the model of straw returning. In Regression 3, the coefficient on the variable "burden period" is positive and statistically significant at the 10% level in the model of comprehensive utilization of livestock manure. These results suggest that farm households in the burden period are inclined to adopt comprehensive utilization of livestock manure technology rather than that of straw returning technology. The reasons underlying these results might be that farm households in the burden period face relatively weak labour constraints and have relatively high risk aversion levels and relatively strong capital constraints. Use of straw returning technology is likely to result in yield loss and a lower income. Comprehensive utilization of livestock manure technology is capital-stabilizing and risk-mitigating, which is more suitable for the production needs of farm households in the burden period. Consequently, they tend to adopt comprehensive utilization of livestock manure technology.

(3) In Regression 2, the coefficient on the variable "stable period" is positive and statistically significant at the 10%, 5%, 5% and 1% levels in the model of water-saving irrigation, commercial organic fertilizer, straw returning and comprehensive utilization of livestock manure, respectively. In Regression 3, the coefficient on the variable "stable period" is positive and statistically significant at the 1%, 1%, 10% and 5% levels in the model of water-saving irrigation, commercial organic fertilizer, straw returning and comprehensive utilization of livestock manure, respectively. These results indicate that farm households in the stable period are more likely to adopt water-saving irrigation technology, commercial organic fertilizer technology, straw returning technology and comprehensive utilization of livestock manure technology. The possible reasons for these results are that farm households in the stable period have abundant and high-quality labour endowments (Li, 2005), relatively abundant capital

(Zhu, Yang, & Rao, 2017), and relatively low risk aversion levels. Thus, farm households at this stage are not only able to meet the capital demand for capital-intensive technologies, such as water-saving irrigation technology, commercial organic fertilizer technology, and straw returning technology but also meet the labour demand for labour-intensive technologies, such as comprehensive utilization of livestock manure technology and commercial organic fertilizer technology. Hence, farm households in the stable period have a high probability of SAT adoption.

(4) In Regression 2, the coefficient on the variable "maintenance period" is positive and statistically significant at the 5% and 1% levels in the model of water-saving irrigation and straw returning, respectively. In Regression 2, the coefficient on the variable "maintenance period" is negative and statistically significant at the 1% level in the model of comprehensive utilization of livestock manure. In Regression 3, the coefficient on the variable "maintenance period" is positive and statistically significant at the 1% and 1% levels in the model of watersaving irrigation and straw returning, respectively. In Regression 3, the coefficient on the variable "maintenance period" is negative and statistically significant at the 1% level in the model of comprehensive utilization of livestock manure. These results suggest that farm households in the maintenance period are inclined to adopt water-saving irrigation technology and straw returning technology rather than that of comprehensive utilization of livestock manure technology. The reasons underlying these results might be that farm households in the maintenance period have relatively weak capital constraints and a relatively strong ability to resist risk (Zhu, Yang, & Rao, 2017), but their work capacity tends to deteriorate (Wang & Wu, 2017). As a result, they tend to adopt mechanical labour-substitution technologies. Comprehensive utilization of livestock manure technology is labour intensive. Water-saving irrigation technology and straw returning technology are capital-intensive and labour-saving, which are more suitable for the production needs of farm households in the maintenance period. Therefore, they tend to adopt water-saving irrigation technology and straw returning technology.

(5) In Regression 3, the coefficient on the variable "empty nest period" is positive and statistically significant at the 10% level in the model of water-saving irrigation. In Regression 3, the coefficient on the variable "empty nest period" is negative and statistically significant at the 10% level in the model of straw returning. These results indicate that farm households in the empty nest period are inclined to adopt water-saving irrigation technology rather than that of straw returning technology. The reason for this fact is that farm households in the empty nest period have relatively strong labour constraints and relatively high risk aversion levels (Su, Feng, & Zhu, 2020), but they still have some capital (Amirtha & Sivakumar, 2018; Li, 2005; Peng & Wu, 2017). Thus, farm households in the empty nest period tend to adopt technologies with relatively few labour demand and low production risk. Although straw returning technology is a labour-saving and risk-mitigating that is more suitable for the production needs of farm households in the empty nest period. Hence, they are more likely to adopt water-saving irrigation technology.

#### 4.1.2. Control variables

Table 3 shows that risk averse, number of labourers, land acreage, household income, adoption benefit and village terrain are significant.

The coefficient on the variable "risk averse" is positive and statistically significant at the 1% and 5% levels in the model of water-saving irrigation and comprehensive utilization of livestock manure, respectively. The coefficient on the variable "risk averse" is negative and statistically significant at the 5% level in the model of straw returning. These results indicate that farm households with high risk aversion levels are inclined to adopt water-saving irrigation technology and comprehensive utilization of livestock manure technology rather than that of straw returning technology. The possible reasons for these results are that water-saving irrigation technology and comprehensive utilization of livestock manure technology are risk-mitigating in contrast to straw returning technology, which meet the production needs of farm households with a high risk aversion level and are thus adopted by these households.

The coefficient on the variable "household income" is positive and statistically significant at the 1% and 1% levels in the model of water-saving irrigation and straw returning, respectively, suggesting that household income is markedly positively correlated with farm households' adoption behaviour for SATs. A possible explanation for this result is that water-saving irrigation technology and straw returning technology are yield-enhancing and capital-intensive, which are more likely to be afforded by farm households with high household income. Thus, these households have a high likelihood of adopting SATs.

The coefficient on the variable "number of labourers" is negative and statistically significant at the 1% and 5% levels in the model of water-saving irrigation and straw returning, respectively. The coefficient on the variable "number of labourers" is positive and statistically significant at the 5% and 10% levels in the model of commercial organic fertilizer and comprehensive utilization of livestock manure, respectively. These results imply that farm households with less labour are more likely to adopt water-saving irrigation technology and straw returning technology, and farm households with larger labour pools are more likely to adopt commercial organic fertilizer technology and comprehensive utilization of livestock manure technology. The main reasons for these results are that water-saving irrigation technology and straw returning technology and straw returning technology are labour-saving. Commercial organic fertilizer technology and straw returning of livestock manure technology and comprehensive utilization of livestock manure technology and comprehensive utilization of livestock manure technology and straw returning technology are labour-saving. Commercial organic fertilizer technology and comprehensive utilization of livestock manure technology and comprehensive utilization of livestock manure technology and comprehensive utilization of livestock manure technology and straw returning technology are labour-saving. Hence, farm households with larger labour pools can meet the labour demand for labour-intensive SATs, while farm households with less labour are more likely to adopt labour-saving SATs.

The coefficient on the variable "land acreage" is positive and statistically significant at the 5% level in the model of water-saving irrigation, suggesting that land acreage is noticeably positively related to farm households' SAT adoption. One likely explanation for this fact is that farm households with large land acreages tend to have long-term agricultural investment activities, expecting to maximize long-term profits and reduce unit costs. Water-saving irrigation technology has a scale effect. That is, the more acres of land receive the application of water-saving irrigation technology, the more benefits are obtained by farm households. As a result, farm households with large land acreage tend to adopt water-saving irrigation technology.

The coefficient on the variable "adoption benefit" is positive and statistically significant at the 10% and 5% levels in the model of commercial organic fertilizer and comprehensive utilization of livestock manure, respectively, indicating that adoption benefit is closely related to farm households' adoption of SATs. The reason for this fact is that farm households are rational. Their technology adoption decisions would take into account the benefit and cost. The more benefits are obtained by farm households, the higher the likelihood of farm households adopting SATs. Commercial organic fertilizer technology and comprehensive utilization of livestock manure technology have the benefits of enhancing crop yields and land productivity and are thus likely to be adopted by households.

The coefficient on the variable "village terrain" is negative and statistically significant at the 1%, 5%, 1% and 1% levels in the model of water-saving irrigation, commercial organic fertilizer, straw returning, and comprehensive utilization of livestock manure, respectively, suggesting that village terrain is closely correlated with farm households' adoption of SATs. One likely explanation for this result could be that mountainous or hilly terrain often leads to rugged countryside roads and increases the difficulty for household members in walking from home to a field or from one field to another field, thereby decreasing the probability of farm households adopting labour intensive technologies, such as commercial organic fertilizer technology and comprehensive utilization of livestock manure technology. Alternately, mountainous or hilly terrain may aggravate the difficulty of mechanical operations and pipeline laying on arable land, thus decreasing the probability of farm households adopting mechanical investment technologies, such as water-saving irrigation technology and straw returning technology.

#### 4.2. Robustness test

The winsorization method was applied to verify the robustness of the above results. The results of this method are shown in Table 4. It is easy to see that the regression results in Table 4 are similar to the results in Table 3, indicating that the results are robust and credible.

# 5. Conclusions and Discussions

Based on survey data from 902 farm households in Hubei Province, China, and taking four SATs as examples, we enrich the literature on agricultural technology adoption behaviour by revealing the role of family life cycle in farm households' SAT adoption decisions with multivariate probit regression analyses. The findings and related policy implications are as follows.

First, family life cycle is influential in farm households' SAT adoption decisions. Farm households have different adoption decisions concerning SAT during different family life cycle stages due to different capital endowments and constraints at each stage. Specifically, farm households in the rearing period and burden period have relatively strong capital constraints and relatively high risk aversion levels and tend to adopt capital-stabilizing and risk-mitigating SATs, such as comprehensive utilization of livestock manure technology. Farm households in the stable period have abundant labour resources, relatively low risk aversion levels, and relatively weak capital constraints, and as a result, they have a high probability of SAT adoption. Farm households in the maintenance period face relatively strong labour constraints and relatively weak capital constraints, and as a result, they tend to adopt labour-saving SATs, such as straw returning technology and water-saving irrigation technology. Farm households in the empty nest period have relatively strong labour constraints and relatively high risk aversion levels and are more likely to adopt labour-saving and risk-mitigating SATs,

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	Water -saving	Commercial	Straw	Comprehensive utilization of	Water -saving	Commercial	Straw	Comprehensive utilization of
Variables	irrigation	organic fertilizer	returning	livestock manure	irrigation	organic fertilizer	returning	livestock manure
Family life	-0.498	-0.089 (0.213)	0.420	0.531* (0.235)				
cycle = rearing period	(0.223)		(0.248)					
Family life	-0.472*	0.058 (0.218)	0.085	0.841*** (0.244)	0.035 (0.156)	0.145 (0.129)	-0.356	0.328* (0.150)
cycle = burden period	(0.233)		(0.254)				(0.153)	
Family life cycle = stable	0.515* (0.232)	0.575** (0.219)	0.884**	0.893*** (0.246)	1.020***	0.661*** (0.129)	0.447*	0.381* (0.151)
period			(0.273)		(0.150)		(0.180)	
Family life	0.590* (0.235)	-0.226 (0.222)	1.244***	-1.460*** (0.302)	1.099***	-0.139 (0.155)	0.792***	-1.968*** (0.241)
cycle = maintenance			(0.273)		(0.172)		(0.203)	
period								
Family life cycle = empty					0.563* (0.231)	0.079 (0.220)	-0.564*	-0.434 (0.244)
nest period							(0.259)	
Control variables		ŭ	ontrolled			5	ontrolled	
Log likelihood		Ĩ	1702.854			Ĩ	1702.677	
Prob > chi <sup>2</sup>			0.000				0.000	
Wald chi <sup>2</sup>			800.40				800.28	

Table 4. Robustness test results.

such as water-saving irrigation technology. Second, most farm households belong to the middle stages of the family life cycle (such as rearing period and stable period), and few farm households belong to the starting period and empty nest period. Third, risk averse, number of labourers, land acreage, household income, adoption benefit, and village terrain also exert impacts on farm households' SAT adoption.

These findings have important implications for the effective promotion of SATs in rural areas. Given that farm households' SAT adoption decisions are closely correlated with family life cycle, and that farm households' adoption decisions concerning SAT differs depending on family life cycle stage, when promoting SATs, the government should take into account the different capital endowments and needs of farm households at different family life cycle stages and provide differential promotion measures that stand in accordance with the characteristics of each family life cycle stage, providing targeted guidance and assistance to increase the probability of SAT adoption. First, specifically considering the fact that most farm households belong to the middle stages of the family life cycle and that farm households at these stages are constrained by capital and have relatively high risk aversion levels, the government should improve the infrastructure and services of health clinics, nursing homes and kindergartens in rural areas to address the worries and burdens caused by teenager parenting and eldercare among these households. Alternately, the government should formulate and implement a series of policies to benefit farm households and provide strong support for financial loans and agricultural insurance to encourage those households to become the main body of modern agricultural production. Second, for farm households in the stable period that do not face obvious capital endowment constraints on SAT adoption, the government should strengthen education and skills training concerning sustainable agricultural production and act to raise the awareness of those households concerning the importance and application of SATs to guide more farm households to join the sustainable agricultural production team. Third, given that farm households in the later family life cycle stages tend to adopt labour-saving SATs due to labour constraints and relatively high risk aversion levels, the government should improve the rural social security and agricultural insurance systems to address the worries concerning risk among these households. Alternately, the government should set up a platform for mutual assistance in agricultural production to help these households obtain services and additional assistants for the tasks of farming and delivering agricultural materials. Furthermore, the government should also vigorously promote research into and development of agricultural machinery suitable for the elderly and produce machinery with high safety measures, simple modes of operation, light weight, and small size to compensate for the labour shortage for agricultural production among elderly farm households through machine substitution. Additionally, we demonstrate the important role of family life cycle in Chinese farm households' SAT adoption decisions, and thus, for countries or regions with low SAT adoption rates, such as Ethiopia or Tanzania (Kassie, Jaleta, Shiferaw, Mmbando, & Mekuria, 2013; Teklewold, Kassie, & Shiferaw, 2013; Zeng, Zhang, He, & Chen, 2019), and concerning countries or regions in which individuals have a strong sense of family, such as South Korea, southern Italy, France, and Latin America (Fukuyama, 1995; Liang, Lin, & Zhang, 2015), it is likely to be beneficial in exploring farm households' consensual technology behaviour from a family life cycle perspective.

Finally, there are some deficiencies in the present study. First, due to data limitations, the present study only discuss the impact of family life cycle stages on the SAT adoption behaviour of farm households at a certain time, whereas the family life cycle changes dynamically. As farm households pass from one family life cycle stage to the next, adoption decisions are likely to vary. Therefore, using panel data to analyze the dynamic influence trends of family life cycle on farm households' SAT adoption could be an interesting research direction. Second, due to the shortage of data at the national level, we fail to observe the influence of regional heterogeneity in the family life cycle. Thus, it is necessary to seek more data to delve deeper in future research.

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#### Notes on contributors

*Fenni Li* is a joint training Ph.D. student in Huazhong Agricultural University and University of Western Australia. Her research focuses on agricultural environmental and resource economics, as well as agricultural technology adoption. She has 10 published articles in peer-reviewed academic journals such as the China Population, Resources and Environment, the Resources Science, and the Journal of Huazhong University of Science and Technology (Social Science Edition) in Chinese.

*Junbiao Zhang* is professor and doctoral tutor at College of Economics & Management, Huazhong Agricultural University. His major research fields include agricultural economic theory and policy, and resource and environment economy. He has published over 200 articles in peer-reviewed academic journals such as the Resources Policy, the Renewable Energy, the China Agricultural Economic Review, and the Economic Research Journal (in Chinese).

*Chunbo Ma* is an associate professor and doctoral tutor at School of Agriculture and Environment, University of Western Australia. His research focuses on environmental economics, resource economics, and agricultural economics. He has published over 50 articles in peer-reviewed academic journals such as the Land Use Policy, the Ecological Economics, and the Australian Journal of Agricultural and Resource Economics.

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144 👄 F. LI ET AL.

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