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Spillovers from modern supply chains to traditional markets: product innovation and adoption by smallholders

Christin Schipmann*, Matin Qaim

Department of Agricultural Economics and Rural Development, Georg-August-University of Göttingen, 37073 Göttingen, Germany

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Abstract

There is an emerging body of literature analyzing how smallholder farmers in developing countries can benefit from modern supply chains. However, most of the available studies concentrate on export markets and fail to capture spillover effects that modern supply chains may have on local markets. Here, we analyze the case of sweet pepper in Thailand, which was initially introduced as a product innovation in modern supply chains, but which is now widely traded also in more traditional markets. Using survey data from smallholder farmers and econometric techniques, we show that sweet pepper cultivation contributes significantly to higher household incomes. Strikingly, at this stage, participation in modern supply chains does not lead to higher incomes than supplying sweet pepper to traditional markets. However, the results also indicate that missing land titles, weak infrastructure conditions, and limited access to information constituted serious constraints during the early phases of sweet pepper adoption. Such constraints need to be overcome, so that smallholder farmers are better prepared for the prompt reactions needed under rapidly changing market conditions.

JEL classifications: C31, C41, O33, Q13

Keywords: Adoption; Duration analysis; Impact assessment; Modern supply chains; Product innovation; Sweet pepper; Thailand

1. Introduction

In many developing countries, agricultural and food systems are undergoing a major transformation toward high-value and modern supply chains. In export markets, standards and certification systems are gaining in importance, while domestically, the role of supermarkets and hypermarkets is growing (Mergenthaler et al., 2009; Reardon et al., 2003; Traill, 2006). There is an emerging body of literature analyzing how smallholder farmers can be linked successfully to such modern supply chains. This literature can be broadly divided into three strands. The first strand focuses on the introduction of nontraditional export crops into the small farm sector, including aspects of adoption and household welfare (Carletto et al., 1999; Singh, 2002; von Braun et al., 1989). The second strand includes more recent studies that analyze the impacts of rising food safety and quality standards in export markets on smallholder farmers (e.g., Asfaw et al., 2009; Henson et al., 2005; Maertens and Swinnen, 2009), while the third strand explores the implications of domestic market changes within developing countries resulting from the establishment of super- and hypermarkets (e.g., Berdegué et al., 2006; Hernández et al., 2007; Neven and Reardon, 2006).

This previous research covers a broad range of important issues. However, most of the available studies examine impacts by only comparing participants and nonparticipants in modern supply chains at a certain point in time. This can be a suitable approach to get a first impression, but it fails to capture two relevant facets: First, participation dynamics are not considered. This can mask important effects, as earlier innovators are often able to reap greater benefits. Second, spillovers that modern supply chains may have on traditional markets are ignored, which might lead to an underestimation of the full benefits. For instance, product innovations, say in the form of nontraditional vegetables, are often first introduced in a country through modern supply chains. If the new product suits domestic production and consumption conditions, it might gradually also penetrate traditional markets, where it can generate additional benefits,

*Corresponding author. Tel.: +49-551-39-4443; fax: +49-551-39-4823. *E-mail address:* cschipm@uni-goettingen.de (C. Schipmann).

Data Appendix Available Online

A data appendix to replicate main results is available in the online version of this article. Please note: Wiley-Blackwell, Inc. is not responsible for the content or functionality of any supporting information supplied by the author. Any queries (other than missing material) should be directed to the corresponding author for the article.

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including for farmers that do not participate themselves in modern supply chains.

We contribute to the literature by analyzing such aspects for the case of sweet pepper in Thailand. Sweet pepper was introduced in Thailand some 10 years ago as a nontraditional vegetable, mainly meant for exports and upscale domestic supermarkets. Yet, over time the product gained wider popularity among domestic consumers, so that it is now traded also in more traditional wholesale and retail markets. Rapidly rising living standards and urbanization tendencies in Thailand have spurred numerous product innovations in the recent past; similar trends are also observable in many other middle-income countries (Swinnen, 2007). Building on primary survey data, we analyze three main aspects. First, we examine what factors generally determine farmers' decisions to adopt sweet pepper as a product innovation. This is done by estimating probit models, whereby the timing of adoption is explicitly considered. Second, by employing a duration model, we look at adoption dynamics and identify factors that favor early adoption. And third, controlling for other factors and taking account of possible nonrandom selection issues, we estimate a treatment effect model to assess the impact of sweet pepper adoption on household income. We also analyze whether the type of marketing channel supplied—modern or traditional—and the timing of adoption matter for the income effect.

The article proceeds as follows. The next section gives some more background about sweet pepper production in Thailand, the particular study region, and the empirical database. Subsequently, the econometric adoption models are developed, estimated, and discussed in the third and fourth section. The fifth section provides the results of the impact analysis, and the last section concludes.

2. Background on sweet pepper cultivation in Thailand and database

2.1. *Sweet pepper cultivation and marketing channels*

Sweet pepper was introduced in Thailand in 1999 by a Dutch company. Because of climatic conditions, the northern upland areas were the primary target regions, especially those near the city of Chiang Mai, where infrastructure and market access conditions were relatively favorable. In particular, the company chose the Mae Sa watershed (Chiang Mai Province), where farmers were contracted to produce red and green sweet pepper in greenhouses, using hydroponics systems that make cultivation independent of soil quality conditions. A major advantage from the company viewpoint was that farmers in the Mae Sa watershed were already familiar with cash crop production. Previously, they had mainly grown cut flowers in greenhouses, complemented by different vegetables or rice. However, sweet pepper cultivation is more labor and input intensive than flower production. It is also associated with higher capital investments, since more sophisticated greenhouses are required. Since farms in the watershed are predominantly small-scale, with an average farm size of 0.7 hectares, the company initially provided credit, private extension, and certain inputs to contracted farmers.

The Dutch company purchases sweet peppers from farmers for exports to Taiwan and China, as well as for sales in modern domestic supply chains. Until 2001, only few farmers had adopted sweet pepper, but afterward adoption rates increased. Gradually, additional companies entered the sweet pepper market, mostly supplying domestic super- and hypermarkets. These companies usually have their preferred farmers in the Mae Sa watershed from whom they buy via formal or informal agreements. A special marketing channel for local farmers is the so-called Royal Project, which started to deal with sweet pepper in 2002. The Royal Project is a subsidized initiative by the King of Thailand to support disadvantaged farmers in the upland areas and offer alternatives to opium production, which was widespread in the 1970s and 1980s. The Project sells vegetables and other agricultural products in upscale outlets under its own brand name, which Thai consumers recognize as being of very high quality. However, only hill tribe farmers, who make up a relatively small part of the population in the Mae Sa watershed, have access to Royal Project marketing channels. In addition to these modern supply chains, traditional village traders increasingly started to deal with sweet pepper through spot-market transactions. They mostly supply regular vegetable wholesale and retail markets in Chiang Mai and Bangkok.

2.2. *Database*

For our empirical study, we conducted a survey of 308 farmers in the Mae Sa watershed in northern Thailand. This watershed is where domestic sweet pepper cultivation had started in 1999, and it is still the main production area for sweet pepper in Thailand. The survey was conducted between May and July 2007. The Mae Sa watershed consists of 22 villages in total, but sweet pepper is cultivated in only nine villages. In these nine villages, all sweet pepper adopters (246 farmers) and 62 randomly selected nonadopters (in total 669 nonadopters live in the nine villages) were interviewed, using a structured questionnaire especially designed for this research. To be able to analyze adoption dynamics, we asked farmers in which year they had started farming in general and sweet pepper cultivation in particular. Similarly, for time-variant variables such as agricultural assets, farm size, or nonfarm occupation, we collected data not only for the status quo in 2007, but also captured changes that occurred in the past since 1999.

Fig. 1 shows that it took several years until sweet pepper was adopted more widely among farmers in the watershed. Considering marketing channels, in the first two years, all adopting farmers sold their sweet pepper to companies under contract, since this was the only available option. The role of the Royal Project increased over time, but its overall market share remains relatively small. Today, traditional village traders constitute the most important marketing channel, and it appears that their entrance into the sweet pepper business was an important trigger for many farmers to adopt this product innovation.

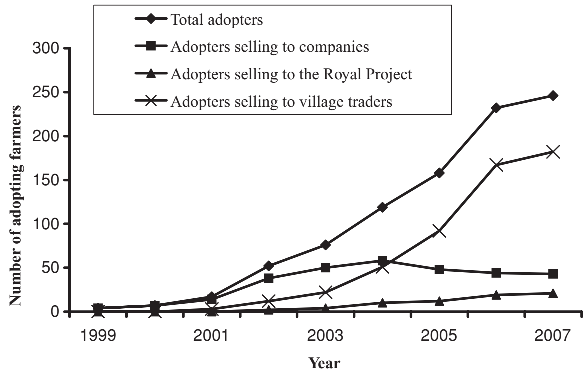

Fig. 1. Sweet pepper adoption and the role of different marketing channels.

Spot-market transactions with village traders are more flexible and less formal than with companies, conditions that many local farmers seem to prefer. And, now that sweet pepper and the production technology have been established in the region, the required inputs can be obtained from different open market suppliers. That is, company contracts are no longer a precondition for producing sweet pepper. These patterns confirm that product innovations might initially be introduced through modern supply chains, but they also demonstrate that spillovers to traditional markets occur with a certain time lag, if the innovation suits local production and consumption conditions on a wider scale.

3. Explaining farmers' adoption decisions

3.1. Comparison of adopters and nonadopters

Adoption of a new product confronts a farmer with new conditions. The more a farmer is able to meet these conditions, the more likely the adoption decision will be positive. Possible adoption constraints can be distinguished into three categories: personal constraints, farm and household constraints, and contextual constraints. The first category covers characteristics such as age and education, the second factors such as farm size, land title, and off-farm occupation, while the third comprises aspects such as road conditions and access to extension services. Earlier studies show that adoption constraints differ according to the particular innovation a farmer is confronted with and the general framework conditions (e.g., Feder et al., 1985; von Braun et al., 1989). Farm size, for example, can play an important role, especially in settings with dual farm structures. Access to capital is especially relevant when the new crop requires increased input use or additional equipment, whereas family labor endowment becomes important when crops require careful treatment and machinery cannot be used (Takane, 2004). When explaining farmers' adoption behavior, such factors have to be considered.

We are interested in explaining the farmers' behavior with respect to sweet pepper adoption in general, but, since the impact of adoption often also depends on the factor time, we attempt to analyze adoption dynamics, too. For this purpose, the group of adopters is disaggregated into three subgroups, each comprising around one-third of the total number of adopters. The first subgroup covers the early adopters, who adopted sweet pepper between 1999 and 2003. The second subgroup includes those who adopted in 2004 or 2005, which is also the time when village traders had entered the market, while the third subgroup consists of the laggards, who adopted sweet pepper between 2006 and 2007. In Table 1, we compare descriptive statistics for the total group of adopters and for each of the subgroups with the group of nonadopters in the respective time period. There are a few individuals in the sample that only started farming recently; they are not included in comparisons referring to earlier time periods.

The comparisons suggest that adopters are more often female and are younger and better educated than nonadopters. Among the farm and household characteristics, having a land title and owning a pick-up truck are variables that are positively correlated with sweet pepper adoption. On the other hand, fewer farm households with off-farm occupations are among the adopters. In terms of the contextual characteristics, contacts to official public extension agents and road conditions are significantly different between adopters and nonadopters. Road conditions are evaluated by the average time it takes to reach the city of Chiang Mai. According to this variable, households are subdivided into those with good, medium, and bad road conditions, each group including three of the nine villages. The magnitude of the differences and the significance levels partly vary over time. Some of the variables, such as extension and road conditions, are particularly important during the early stages of adoption, while others, such as education and land titles, remain important over the entire period. We further investigate these differences in the following econometric analyses.

3.2. Specification of probit adoption models

Differences in mean values, as analyzed in Table 1, should not be overinterpreted, since possible confounding factors are not controlled for. This requires appropriate regression models. For the purpose of explaining adoption behavior, estimation of probit models is a common approach (Gregg, 2009; McFadden, 1980). Table 2 shows results of different probit models, where sweet pepper adoption is defined as a binary variable. Model 1 estimates adoption behavior using the entire group of adopters, that is, the dependent variable takes a value of 1 if sweet pepper was adopted until 2007 and is 0 otherwise. The covariates include the farm, household, and contextual characteristics discussed above, plus other variables that are commonly used in the innovation adoption literature (Abdulai and Huffman, 2005; Feder et al., 1985). Models 2 to 4 have the same specification, but they are run with different subsamples to capture changes over time. Model 2 refers to the early stage of adoption, that is, all households that adopted until 2003 are considered as adopters, and all other households as nonadopters. Model 3 refers to adopters in 2004 and 2005, while model 4 explains adoption in 2006 and 2007. In these latter two models, farmers who had adopted before the respective time period are dropped.

Table 1
Descriptive statistics for different groups of adopters and nonadopters

Variables	Nonadopter 1999–2003 ($N = 189$)	Adopter 1999–2003 ($N = 76$)	Nonadopter 1999–2005 ($N = 131$)	Adopter 2004–2005 ($N = 81$)	Nonadopter 1999–2007 ($N = 62$)	Adopter 2006–2007 ($N = 88$)	Adopter 1999–2007 ($N = 246$)
Characteristics of the person responsible for farming decisions							
Female (%)	40.7	47.4	42.8	40.7	33.9	50.0**	46.1*
Age in years	41.0	37.0***	42.8	39.9**	47.6	41.2***	39.5***
	(10.1)	(8.0)	(10.7)	(10.1)	(11.6)	(9.7)	(9.5)
Education in years of schooling	5.8	7.2***	5.6	6.8***	4.6	6.7***	6.7***
	(2.9)	(3.7)	(2.9)	(3.3)	(2.7)	(3.0)	(3.3)
Farm and household characteristics							
Land owned in rai[a]	4.2	4.0	4.7	3.1*	3.8	4.5	3.9
	(6.4)	(6.9)	(7.3)	(3.6)	(5.4)	(7.8)	(6.4)
Area cultivated in rai	3.9	4.6	4.5	2.7**	3.8	4.3	3.9
	(7.0)	(14.1)	(8.2)	(2.7)	(5.0)	(9.3)	(9.8)
Area under sweet pepper in rai	–	1.6	–	1.4	–	1.1	1.3
		(1.0)		(1.1)		(1.1)	(1.1)
Land title (%)	72.0	88.2***	65.7	84.0***	58.1	76.1**	82.5***
Pick-up truck (%)	38.1	52.6**	38.2	43.2	29	53.4***	49.8***
Off-farm occupation (%)	47.1	31.6**	56.5	35.8***	58.1	51.1	40.0***
Contextual characteristics							
Member in a farm group (%)	5.8	2.6	7.6	4.9	6.5	10.2	5.3
Extension contact (%)	10.1	29***	9.16	14.81	3.2	11.4*	18.0***
Good road conditions (%)	63.0	96.1***	55	82.7***	54.8	59.1	78.4***

Notes: Mean values are shown. For continuous variables, standard deviations are shown in parentheses.
[a]One rai equals 0.16 hectares.
*, **, and *** indicate differences are significant at the 10%, 5%, and 1% level, respectively. Differences are always tested between adopters and nonadopters in a particular time period. The total group of adopters is tested against the total group of nonadopters in 1999–2007.

To avoid statistical and interpretation problems, time-variant variables need special treatment. For adopters, we set all values back to the individual time of adoption, whereas for nonadopters we use the values at the end of the respective time period. These adjustments are, as mentioned above, based on recall data that we elicited during the survey. The alignment of time-variant variables also allows us to address potential problems of reverse causality. For instance, agricultural assets might increase the probability of sweet pepper adoption, but, on the other hand, adoption might also entail asset accumulation. Indeed, when estimating our models without taking account of time-variant factors (i.e., assuming 2007 values for all variables), the estimates for agricultural assets turned out to be positive and significant, while they are not significant in any of our improved specifications.

3.3. Estimation results

The estimation results for the four models are shown in Table 2. The coefficients in model 1 largely confirm the results from the descriptive statistics. Age negatively influences adoption behavior, whereas education has a positive impact. Given the complexity of sweet pepper cultivation (i.e., greenhouses with hydroponics systems), it is understandable that younger and better-educated farmers are more likely to adopt the innovation. This is a common finding in the agricultural innovation adoption literature (e.g., Abdulai and Huffman, 2005; Dadi et al., 2004; D'Emden et al., 2008; Rahman et al., 2009).

Another widely discussed variable in the adoption literature is farm size. As smallholder farmers are among the poorest households in developing countries, empirical studies often pay special attention to this particular group. Whereas some innovations and framework conditions favor adoption by larger farms, the opposite holds true in other situations (e.g., Matuschke and Qaim, 2008). However, interpretations should be done with care, as farm size is often correlated with or even used as a proxy for other factors such as wealth, access to credit, or risk aversion (Carletto et al., 2007; Feder et al., 1985; Reardon et al., 2009). In our case, farm size has a positive but very small effect on adoption. This is plausible, as most farmers in the watershed are smallholders anyway, so that substantial economies of scale can hardly be observed.

Although sweet pepper cultivation is quite labor intensive, the family labor endowment does not seem to influence adoption significantly. Yet it is also important to consider whether there are alternative income sources for family members that could potentially prevent them from spending substantial time in farming. Indeed, Table 2 shows that households with off-farm occupation are less likely to adopt sweet pepper, suggesting that there is a certain competition for labor within households. A similar result was also reported by Hernández et al. (2007) in Guatemala.

Considering the contextual variables, medium and bad road conditions reduce the probability of adoption, whereas contacts with agricultural extension agents and ownership of a pick-up truck increase the probability. In other words, market and

Table 2
Determinants of sweet pepper adoption

Variable	Model 1 (Adoption 1999–2007)	Model 2 (Adoption 1999–2003)	Model 3 (Adoption 2004–2005)	Model 4 (Adoption 2006–2007)
Education (years)	0.02***	0.02**	0.04**	0.05**
	(0.01)	(0.01)	(0.02)	(0.02)
Female (dummy)	0.04	−0.02	−0.13*	0.13
	(0.03)	(0.06)	(0.07)	(0.09)
Age (years)	−5E-03***	−6E-03*	−1E-05	−1E-02**
	(2E-03)	(3E-03)	(4E-03)	(6E-03)
Land owned (rai)	7E-03**	7E-03	−4E-03	2E-01
	(3E-03)	(4E-03)	(7E-03)	(7E-02)
Land title (dummy)	0.04	0.01	0.06	0.09
	(0.04)	(0.08)	(0.10)	(0.11)
Family labor endowment (No. of household members between the age of 14 and 65 years)	−0.01	−0.02	0.04	−0.06*
	(0.01)	(0.03)	(0.03)	(0.04)
Off-farm occupation (dummy)	−0.19***	−0.18***	−0.28***	−0.22**
	(0.05)	(0.05)	(0.07)	(0.09)
Info source trader/dealer[a] (dummy)	−0.09**	0.01	0.04	0.03
	(0.03)	(0.06)	(0.09)	(0.10)
Medium road conditions[b] (dummy)	−0.10*	−0.25***	−0.25***	−0.04
	(0.08)	(0.04)	(0.07)	(0.13)
Bad road conditions[b] (dummy)	−0.35***	−0.27***	−0.37***	−0.26*
	(0.12)	(0.04)	(0.07)	(0.15)
Member in a farm group (dummy)	0.01	−0.14	−0.24**	0.17
	(0.06)	(0.07)	(0.08)	(0.11)
Extension contact (dummy)	0.11***	0.34***	0.19*	0.36***
	(0.03)	(0.10)	(0.11)	(0.07)
Value of nonland agricult. assets (100 thsd. Baht)	−2E-03	−0.03	−0.06	−0.05
	(2E-02)	(0.05)	(0.08)	(0.07)
Value of other assets (100 thsd. Baht)	0.03	−0.03	−0.11	0.14*
	(0.03)	(0.04)	(0.07)	(0.08)
Pick-up truck (dummy)	0.13***	0.13**	0.13	0.34***
	(0.04)	(0.06)	(0.08)	(0.09)
Number of observations	307	265	212	150
Wald $\chi 2$	77.90***	63.62***	48.35***	47.37***
Pseudo R^2	0.37	0.28	0.22	0.29

Notes: Coefficient estimates are marginal effects. Robust standard errors are shown in parentheses.
*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.
[a]The reference variable is farmers who have persons other than the trader/input dealer as a main source of information.
[b]The reference variable is good road conditions.

information accessibility have a positive influence on adoption, which is as expected and was shown in other studies as well (Gregg, 2009; Maertens and Swinnen, 2009; Randela et al., 2008). But also the source of information matters. If traders and input dealers are the primary source of information for a farmer on production and marketing aspects, the likelihood of sweet pepper adoption is reduced. This is similar to findings by Burton et al. (2003) in a different context. In the local setting in Thailand, traditional traders and input dealers do not seem to be important multipliers of information related to sweet pepper, which is plausible because the product innovation was initially introduced through other channels. The reference for the trader/dealer dummy is farmers who have other persons—such as neighboring farmers or village heads—as an important source of information. This suggests that informal social networks might also play an important role for innovation adoption, which was shown more explicitly by Matuschke and Qaim (2009) among smallholders in India.

Models 2 to 4, which analyze the effects during different stages of adoption, give additional insights. Some of the variables, such as education and off-farm occupation, have a fairly consistent influence on adoption during all periods. Other variables, however, show notable differences between the models. For medium and bad road conditions, the effects on the probability of sweet pepper adoption seem to decline over time. That is, good road conditions matter especially during the early adoption stages. This makes sense because specialized companies were initially the only available marketing channel for sweet pepper in Thailand, and these companies primarily contracted farmers in easily accessible locations, in order to limit transaction costs associated with extension and monitoring. However, once information about sweet pepper production became more widely available, and traditional traders entered the market, some of the initial constraints have lost in importance.

Trends observed for the coefficients of age, pick-up truck, and extension show a somewhat different picture. Contact to a public agricultural extension agent and ownership of a pick-up truck positively influence adoption behavior in an early and late stage of adoption, whereas there is no significant effect in the years in-between. The same is true for age, with younger farmers being more likely to adopt in the first and in the last model. This pattern reflects a change in market and marketing conditions as well. Whereas the spread of information and establishment of traditional traders offered better framework conditions for sweet pepper adoption, dissolving some of the initial constraints, increasing numbers of adopters in more recent years entail occasional oversupplies and higher price volatility and market risk. Under these new conditions, some of the early adoption constraints seem to re-gain in importance. As sweet pepper is only a niche product in Thailand, market prices respond immediately to fluctuating supplies.

4. Explaining adoption dynamics

4.1. Background on duration models

Standard adoption models, like the ones estimated above, can only identify factors that influence an individual's decision to adopt or reject an innovation. They cannot properly explain the individual timing of an adoption decision, meaning the time a farmer takes until he/she adopts an innovation. Our approach of categorizing adopters and estimating models at different points in time may capture some of the dynamics, but the models themselves remain static nonetheless. Also within adopter categories, heterogeneity in the time of adoption is observed. Moreover, certain farmers who only started farming some time during the period of observation cannot easily be categorized by standard static adoption models. To better understand possible adoption constraints and the role they play over time, use of dynamic models is instructive. One promising approach is the employment of duration models (Abdulai and Huffman, 2005; Burton et al., 2003; Carletto et al., 1999; Fuglie and Kascak, 2003; Matuschke and Qaim, 2008). Duration models explicitly explain the adoption spell, that is, they help identify factors that have a significant effect on the time it takes an individual to adopt an innovation.

The basic idea of a duration model is to estimate the probability that an individual changes, at the beginning of time period t, its position from one stage (nonadoption) to another (adoption), given that the individual has not entered that stage until the beginning of t. This probability is reflected by the hazard function, which can be thought of as the continuous time version of a sequence of conditional probabilities (Burton et al., 2003). In innovation adoption studies, the hazard function therefore represents the probability that a farmer adopts the innovation at time t, conditioned on the fact that the farmer has not adopted the innovation before t (Dadi et al., 2004). The hazard rate that the individual faces is a function of the baseline hazard and a vector of variables that shifts the hazard multiplicatively.

The baseline hazard can be described by different distribution functions—such as the Weibull, exponential, or Gompertz—which vary with respect to the course of adoption; the choice of the most suitable functional form is an empirical problem. A good indicator is the Akaike information criterion (AIC), which should be as low as possible (Cleves et al., 2002). For parametric duration models, the AIC is defined as $AIC = -2\ln L + 2\,(k + c)$. The term $-2\ln L$ is the log-likelihood value of the model, k equals the number of independent variables, and c is the number of model-specific distribution parameters. The latter is equal to 1 for the exponential distribution and equal to 2 for the Weibull and Gompertz distribution. Once an appropriate parameterization is selected, estimation follows maximum-likelihood principles (Greene, 2003).

4.2. Specification of the duration model

In our case, the innovation is sweet pepper production and the adoption spell is measured in years (1999 until 2007). We set up our data in a discrete time fashion in which each farmer is represented by one to multiple rows according to the number of years it took him/her to adopt (one row for every year of the adoption spell). For farmers who started farming before 1999, when sweet pepper production was introduced, the adoption spell comprises the time between 1999 and the year of adoption. For farmers who started farming later than 1999, the adoption spell is the time from the start of the farming business until the time of adoption. For the baseline hazard, using the AIC, we chose a parametric model with a Gompertz distribution. This implies that the hazard rate is either exponentially increasing or decreasing with time.

For model estimation, we include 245 farmers who adopted sweet pepper and 62 farmers who did not. For the latter, the adoption spell is not completed as adoption did not take place yet. In this case, the observations are right-censored, indicating that the process is ongoing (Burton et al., 2003; Cleves et al., 2002). The dependent variable is sweet pepper adoption. It equals 0 in all years where sweet pepper was not adopted and 1 in the year of adoption. The explanatory variables are the same as in the probit models above. However, the time-variant variables are included in a more precise manner. Instead of setting the value of a variable back to a certain point in time, duration models allow us to specify the value of a variable for each year of the observation period. The time-variant variables in our model are age, family labor endowment, off-farm occupation, membership in a farm group, ownership of a pick-up truck, value of agricultural assets, and value of nonagricultural assets.

4.3. Estimation results

Table 3 displays the estimation results of the duration model. The coefficients are interpreted as effects on the hazard rate of adoption. A positive coefficient has a positive impact on the

Table 3
Parametric estimation of the hazard rate of adoption

Variable	Coefficient	Standard error	Hazard ratio[d]
Education (years)	0.11***	0.01	1.12***
Female (dummy)	−0.02	0.07	0.98
Age (years)	−0.03***	3E-03	0.98***
Land owned (rai)	0.05	0.04	1.06
Land title (dummy)	0.31***	0.08	1.36***
Family labor endowment (No. of household members between the age of 14 and 65 years)	1E-05	0.03	1.00
Off-farm occupation (dummy)	−0.61***	0.07	0.54***
Info source trader/dealer[a] (dummy)	−0.48***	0.06	0.62***
Medium road conditions[b] (dummy)	−0.67***	0.08	0.51***
Bad road conditions[b] (dummy)	−0.96***	0.11	0.38***
Member in a farm group (dummy)	0.51***	0.08	1.67***
Extension contact (dummy)	0.75***	0.09	2.11***
Value of nonland agricult. assets (100 thsd. Baht)	−0.09	0.06	0.91
Value of other assets (100 thsd. Baht)	0.11***	0.03	1.11***
Pick-up truck (dummy)	0.55***	0.07	1.74***
Constant	−4.48***	0.22	–
Gamma[c]	0.52***	0.02	0.52***
Log-likelihood	−970.16		−970.16

*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Standard errors are robust.
[a]The reference variable is farmers who have persons other than the trader/input dealer as a main sources of information.
[b]The reference variable is good road conditions.
[c]The positive value for gamma indicates that the hazard rate is exponentially increasing.
[d]The hazard ratio is calculated as exp(coefficient).

hazard rate, that is, it speeds up the adoption process and *vice versa*. Table 3 also shows hazard ratios calculated from the coefficients. A ratio bigger/smaller than 1 speeds up/slows down the adoption process; subtracting 1 from the hazard ratio results in the marginal effect of the variable on the hazard rate of adoption. The estimates show that education speeds up adoption significantly. This is consistent with findings from previous duration analyses with respect to other agricultural innovations (Abdulai and Huffman, 2005; Fuglie and Kascak, 2003; Matuschke and Qaim, 2008). One year of additional education increases the hazard rate of adoption by 12%. In contrast, age has a negative impact; an increase by one year decreases the adoption hazard by 2%. Looking at farm characteristics, we find that land title is more important than size of land owned. The first increases the hazard rate of adoption by 36%, whereas the latter does not show any significant effect at all. This is not surprising. Sweet pepper cultivation is associated with longer-term investments in greenhouse facilities. Holding a land title reduces uncertainty, improves access to formal credit, and allows farmers to take a longer planning horizon.

Based on the probit results above and also the findings from other studies (Burton et al., 2003; Matuschke and Qaim, 2008), we expect access to markets to have a significant effect on sweet pepper adoption. Indeed, unfavorable road conditions slow down the adoption process. Compared to good road conditions, medium and bad road conditions decrease the adoption hazard by 49% and 62%, respectively. In a similar fashion, ownership of a pick-up truck increases the adoption hazard. The large coefficient indicates that pick-up truck ownership is a particularly important variable. Especially in the first years, when there were no alternative marketing channels, adopting farmers had to transport sweet peppers to the pack house of the Dutch company themselves.

While the important role of information was already apparent in the probit models, it comes out even more clearly here. Contact with extension agents has the largest positive effect on the speed of adoption, but also more informal information exchange through farmer groups speeds up sweet pepper adoption significantly. By contrast, farmers who mainly rely on traders or input dealers as sources of information have adopted much more slowly. This makes sense, as traditional village traders themselves entered the sweet pepper market only with a time lag of several years.

Contrary to Carletto et al. (2007), we find that nonland agricultural assets do not affect the speed of adoption, while nonagricultural assets do. Previous investments in agriculture are not important, because the hydroponics technology for sweet pepper is quite special, so that existing equipment is only of limited use. In contrast, a higher value of nonagricultural assets, which is an indicator of household wealth, speeds up the adoption process significantly.

5. Impact of sweet pepper adoption

5.1. *Specification of the income model*

In addition to explaining adoption, we are interested in the impact of sweet pepper cultivation on income. Usually, farmers only adopt an innovation if it is profitable for them, so that the effect on farm income should be positive (Feder et al., 1985). However, in order to be able to also capture indirect effects and potential resource reallocations within households, we analyze the impact on total household income rather than farm income alone. In the survey, income data were collected in a disaggregate fashion, including all agricultural and nonagricultural activities of all household members over a 12-month period. In our impact models, we use total annual household income as the dependent variable (measured in thousand Thai Baht) and sweet pepper adoption as the treatment variable, while controlling for other factors that might influence the outcome.[1]

At first, we estimate a simple OLS regression, employing a dummy for sweet pepper adoption. However, since adoption in our sample is not random, we might face a selection problem, leading to a biased estimate of the effect of sweet pepper adoption on household income. Following Miyata et al. (2009) and Bolwig et al. (2009), we account for this by using a treatment effect model, also called the Heckman selection correction model (Greene, 2003), which involves two equations. The first is the adoption equation, which estimates the probability of sweet pepper adoption; the second is the outcome equation, which estimates household income as a function of various farm and household characteristics. The latter also includes a dummy variable for sweet pepper adoption and a correction term calculated from the first equation that adjusts the outcome equation for a possible selection bias.[2]

For model estimation, we implement a full information maximum likelihood procedure. The adoption equation is derived from the probit models discussed above (Table 2). Many of the variables in this model also appear in the outcome equation, while others do not, which is important for proper model identification. Separate tests revealed that ownership of a pick-up truck and the road condition dummies, which are significant in the adoption equation, do not have a direct effect on household income, so we use these variables as instruments.

5.2. Results

The results of the OLS and the treatment effect model are shown in Table 4. For the treatment effect model, the parameter ath(ρ) at the bottom of the table is the inverse hyperbolic tangent of ρ. The latter captures the correlation between the error terms in the adoption and outcome equation. If ath(ρ) is significant, a selection bias exists, whereas an insignificant parameter points at no selection bias. Here, ath(ρ) is not significant, indicating that the OLS model leads to unbiased estimates. Therefore, this is our preferred model.

[1] Households that had adopted sweet pepper only in 2007 are dropped from this analysis, because for them the 12-month income data partly refers to the situation before adoption.

[2] As an alternative to this treatment effect model, one could use propensity score matching (PSM) to control for selection issues. Yet, in our context, we prefer the treatment effect model, because there may also be unobservable factors that influence sweet pepper adoption, whereas the PSM approach assumes that farmer heterogeneity is only due to observable factors.

Sweet pepper adoption has a positive impact on household income. All other things equal, cultivating sweet pepper increases annual income by 112,000 Baht (US \$3,397). Mean annual income in the sample is 261,980 Baht, so that adoption of sweet pepper cultivation leads to an increase by 43%. This is a substantial effect, demonstrating that product innovations can indeed improve the situation of smallholder farmers. Our findings are in line with results from earlier studies on adoption of high-value crops. von Braun et al. (1989) showed that non-traditional export crops are substantially more profitable than traditional crops in Guatemala, a result that was later confirmed by Carletto et al. (2007) in the same setting. In a similar fashion, McCulloch (2002) and Maertens and Swinnen (2009) found a positive impact of export horticulture production on household income in Kenya and Senegal, respectively.

Besides production of high-value crops, much attention has recently been paid to the differentiation of marketing channels. Yet, research that empirically examines the effects of different marketing channels on total household income remains rare. Most studies are confined to the partial incomes of particular agricultural enterprises. Many of them show that integration in modern supply chains results in higher net earnings for the respective crop (Asfaw et al., 2009; Berdegué et al., 2006; Natawidjaja et al., 2007; Neven and Reardon, 2006; Roy and Thorat, 2008). However, Hernández et al. (2007) find that profits are roughly the same for farmers participating in supermarket and traditional market channels. We use two additional variables—namely, Royal Project and company supply chain dummies—to analyze whether the choice of marketing channel has an important impact on the income of sweet pepper farmers in Thailand.

As Table 4 shows, supplying sweet pepper to the Royal Project has a significantly positive effect on household income. However, as mentioned above, this marketing channel is partly subsidized and only accessible for certain hill tribe minorities, so that it cannot be considered a model for large-scale expansion. Strikingly, however, company supply chains, which only include farmers supplying sweet pepper to private companies, do not show a significant impact. This should not be misinterpreted as evidence that modern supply chains cannot contribute to income growth and development in this particular context. On the contrary, sweet pepper in Thailand was initially introduced through modern supply chains, and, as shown, adoption of this product innovation contributes substantially to the increases in household income. Yet, over time, these benefits of modern supply chains have spilled over also to traditional markets, such that today the type of marketing channel does not matter anymore. It is not surprising, hence, that most of the sweet pepper farmers now sell their produce to traditional village traders through spot-market transactions, which offer greater flexibility. Overall, these results suggest that only comparing the incomes of modern supply chain participants and nonparticipants at a certain point in time, as done in many previous studies, can lead to significant underestimation of the overall effect.

Table 4
Impact of sweet pepper adoption on household income

Variable	OLS		Treatment effect model	
	Coefficient	Standard error	Coefficient	Standard error
Sweet pepper adoption (dummy)	1.12*	0.61	1.73**	0.87
Royal Project (dummy)	2.13**	1.13	2.13*	1.10
Company supply chain (dummy)	−0.07	0.56	−0.08	0.54
Female (dummy)	−0.16	0.38	−0.21	0.39
Age (years)	−0.04*	0.02	−0.03	0.02
Education (years)	−0.02	0.09	−0.03	0.09
Value of nonland agricult. assets (100 thsd. Baht)	0.31	0.27	0.30	0.27
Value of other assets (100 thsd. Baht)	0.65**	0.30	0.64**	0.30
Land owned (rai)	0.03	0.04	0.03	0.04
Land title (dummy)	0.78	0.51	0.67	0.50
Family labor endowment (No. of household members between the age of 14 and 65 years)	0.04	0.17	0.04	0.16
Info source trader/dealer (dummy)	0.63*	0.36	0.68*	0.36
Off-farm occupation (dummy)	0.72**	0.38	0.81**	0.40
Extension contact (dummy)	−1.13**	0.42	−1.24***	0.44
Constant	1.12	1.76	0.54	1.97
ath(ρ)	–	–	−0.15	0.14
F-statistics/Wald χ^2	3.51***		42.24***	

Notes: The dependent variable is household income, which is measured in 100 thsd. Baht per year. The number of observations is 288.
*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.
Standard errors are robust.

The other coefficient estimates in Table 4 highlight that off-farm occupation and the value of nonagricultural assets have the expected positive impact on household income. Additionally, having the trader/input dealer as the main source of information influences net income positively. This is interesting, because the same variable had a negative effect on sweet pepper adoption. Obviously, traditional traders and input dealers are not the best source of information when it comes to new supply chain opportunities, but having good relations with them is still advantageous from an income perspective. It would be interesting here to analyze the situation over time, as it might well be that the trader/dealer effect was different previously, when sweet pepper was not yet traded in traditional markets. Unfortunately, however, we do not have detailed income data for previous years, as these are very difficult to obtain in a recall survey. Somewhat surprisingly, having contacts with extension agents has a negative net impact on household income, although this variable positively influences sweet pepper adoption. This suggests that public extension agents are a good source of information for innovations in general, but they are rather ineffective in assisting farmers to implement profit-increasing cultivation or marketing practices. This is plausible for the example analyzed, as sweet pepper comes along with new cultivation technologies that were introduced by the private sector. These findings point at scope for improvement in the public extension service.

Table 5
Impact of timing of sweet pepper adoption on household income (OLS)

Variable	Coefficient	Standard error
Sweet pepper adoption, early (dummy)	2.04**	0.80
Sweet pepper adoption, middle (dummy)	1.30**	0.64
Sweet pepper adoption, late (dummy)	0.46	0.66
Royal Project (dummy)	2.23**	1.10
Company supply chain (dummy)	0.01	0.54
Female (dummy)	−0.09	0.39
Age (years)	−0.03	0.02
Education (years)	−0.03	0.09
Value of nonland agricult. assets (100 thsd. Baht)	0.23	0.28
Value of other assets (100 thsd. Baht)	0.55**	0.28
Land owned (rai)	0.03	0.04
Land title (dummy)	0.67	0.51
Family labor endowment (No. of household members between the age of 14 and 65)	0.02	0.16
Info source trader/dealer (dummy)	0.57	0.36
Off-farm occupation (dummy)	0.88**	0.37
Extension contact (dummy)	−1.40***	0.43
Constant	1.29	1.77
F-statistic	4.13***	

Notes: The dependent variable is household income, which is measured in 100 thsd. Baht per year. The number of observations is 288.
*, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.
Standard errors are robust.

Table 5 shows results of an additional model in which we disaggregate the adoption variable into separate dummies for early (1999–2003), middle (2004–2005), and late adopters (2006–2007). As one would expect, the timing of the adoption decision matters, with earlier adopters gaining significantly more than later adopters. This is in line with findings by Carletto et al. (2007) from their study in Guatemala. In our case, early adoption increases household income by 204,000 Baht (6,172 US$) or 78% compared to the sample mean. Adoption in the middle period increases income by 50%, whereas the effect for late adopters is not significant anymore. Results for the other variables are comparable to those in Table 4. As pointed out above, we only have income data for one year, so we do not know how the adoption benefits as such developed over time.

The fact that the early adopters still benefit more today than their later-adopting colleagues is probably due to the longer experience that they have with the innovation, potentially resulting in higher production and marketing efficiency. It would be interesting to analyze such aspects more explicitly in follow-up research.

6. Conclusions

We have analyzed the adoption and impacts of sweet pepper cultivation among smallholder farmers in Thailand. The crop was introduced in the country some 10 years ago as a product innovation, mainly meant for exports and upscale domestic supermarkets. During the initial years, specialized companies were the only available marketing channel; these companies primarily contracted northern upland farmers in easily accessible locations, in order to limit transaction costs associated with private extension and monitoring. Accordingly, bad infrastructure and transport conditions, as well as limited access to good information, constituted serious adoption constraints in the beginning and slowed down the adoption process. Over time, sweet pepper gained wider popularity among Thai consumers, so that it is now traded also in more traditional wholesale and retail markets. Information about sweet pepper production became more widely available, and village traders entered the market, so that some of the initial adoption constraints for farmers were eased.

Our impact analysis has shown that sweet pepper cultivation contributes significantly to higher household incomes. This underlines that adopting product innovations can be an important avenue for smallholder farmers to improve their situation. Strikingly, at this stage of the innovation diffusion process, supplying sweet pepper to modern supply chains does not lead to higher incomes than supplying to traditional markets. This suggests that, at the current stage of market development, the product innovation as such matters more than the type of supply chain. Although product innovations in developing countries are often introduced initially through modern supply chains, positive spillovers to traditional markets occur. Our findings indicate that such spillovers should not be underestimated; they need to be accounted for in future studies of the wider implications of modern supply chains.

However, further market differentiation can be expected in the future, and the positive income effects for farmers participating in the Royal Project suggest that additional benefits can be realized when selling in the top tier of modern supply chains. Hence, the question as to how smallholder farmers can access these market segments on a wider scale must not be overlooked from a development perspective. Furthermore, even though spillovers from modern supply chains might lead to better innovation access and positive income effects also in traditional markets, disadvantaged farmers will only benefit with a time lag. And, our results show that even after adoption the benefits are much smaller for late adopters than they are for early adopters. Therefore, to avoid negative income distribution effects, it is a policy challenge to overcome the initial adoption constraints for disadvantaged farmers, and help them to better link to modern supply chains. In the particular case analyzed here, concrete recommendations include addressing infrastructure weaknesses and transportation problems, granting land titles to farmers, and improving their access to proper information.

In general, the agricultural and food system transformation in developing countries will lead to faster changing market conditions in the future. Policy support is needed to make smallholder farmers better prepared for the dynamic adaptations needed, in order to maintain and increase their competitiveness.

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