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Do remotely-sensed vegetation health indices explain credit risk in agricultural microfinance?

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Abstract

Farmers' vulnerability to adverse weather events, which are likely to increase in frequency and magnitude due to climate change, is a major impediment to a sufficient credit supply. Smallholder farmers' access to credit is, among other factors, crucial for productivity and output growth. Index insurance could help lenders to compensate for lacking installment payments in years with severe weather conditions and, thus, is considered to accelerate agricultural lending. Using a unique borrower dataset provided by a Microfinance Institution (MFI) in Madagascar, we analyze whether remotely-sensed vegetation health indices can explain the credit risk of the MFI's agricultural loan portfolio. Therefore, we utilize sequential logit models and quantile regressions. More specifically, we consider the remotely-sensed Vegetation Condition Index, Temperature Condition Index and the Vegetation Health Index as independent variables at the individual branch and the aggregated bank level. These indices are available globally and can potentially enhance the effectiveness of index insurance by reducing basis risk, a major drawback of index insurance. Moreover, we consider loan- and socio-demographic variables of the borrowers as additional independent variables. Our results show that the credit risk of the MFI is explained, to a large extent, by the vegetation health indices. Moreover, the results from quantile regressions show that the explanatory power of the vegetation health indices increases with increasing credit risk. Thus, utilizing remotely-sensed vegetation health indices for index insurance designs might be particularly valuable for MFIs to hedge the credit risk of their agricultural loan portfolio. Facing lower default rates, MFIs could reduce interest rates. Remotely-sensed index insurance could therefore enhance access to credit, contributing to sustainable development in the study region.

Keywords: Remotely-sensed data, Vegetation Health Indices, Credit risk, Microcredit, Index insurance

1 Introduction

Covariate shocks related to weather perils can heavily affect poor smallholder farmers' welfare since they are typically unable to cope with these perils. Formal insurance is often absent while informal insurance only offers partial risk protection. Informal risk-sharing networks in which the participating farmers provide help to each other in times of need are effective at managing idiosyncratic risks. However, if risk exposure is covariate, for example in the case of extreme weather events, there will be no opportunity for risk pooling through informal risk management tools. Covariate risks lead to income reductions for all farmers in a specific region (Barnett, Barrett, & Skees, 2008; Sawada, 2007). Access to insurance is often identified in the literature as a way for smallholder farmers to emerge from poverty not least by enabling access to credit (Barnett et al., 2008, Carter, Cheng, & Sarris, 2011; Farrin & Miranda, 2015; Giné & Yang, 2009; Mahul & Skees, 2007; Platteau, De Bock, & Gelade, 2017). Due to weather related risks such as droughts, agricultural loan portfolios are regarded to be riskier than urban loan portfolios (Giné & Yang, 2009; Miranda & Gonzalez-Vega, 2010).

Against this background, index insurance has gained widespread interest as a valuable risk management tool in the development economics literature (Barnett et al., 2008; Carter, 2009; Negenborn, Weber, & Musshoff, 2018; Skees, 2008). Unlike conventional indemnity-based insurance, index insurance compensates the insured farmer if an index (e.g. rainfall or temperature), correlated with the farmers' losses, reaches a specific threshold value (Miranda & Gonzalez-Vega, 2010). Index insurance addresses the difficulties associated with conventional indemnity-based insurance. Since the index value cannot be influenced by the farmers, index insurance is free from moral hazard. Additionally, index insurance is barely affected by adverse selection since indemnity payments are based on objectively measurable variables. This leads to comparably low transaction costs (Carter, Janvry, Sadoulet, & Sarris, 2017; Farrin & Miranda, 2015; Skees, 2008). However, the advantages compared to conventional indemnity-based insurance come at the cost of the so-called basis risk, an imperfect correlation between the contractually defined index and the insured's actual losses. The policy holder might experience damage and not receive a payout or vice versa (Farrin & Miranda, 2015; Skees, 2008; Woodard & Garcia, 2008). Thus, the most important criterion for choosing a reasonable underlying index is a high correlation with the returns generated from the insured variable, which is in most cases approximated by the crop yield.

Common underlying indices for index insurance are based on weather station data. The literature mainly refers to precipitation or temperature sums over certain accumulation periods (Giné & Yang, 2009; Leblois, Quirion, Alhassane, & Traoré, 2014). With regard to the weather induced credit risk of agricultural loan portfolios in less developed countries, Negenborn et al. (2018) provide evidence that MFIs could benefit from the use of index insurance. The authors find that the credit risk of agricultural loan portfolios can be more adequately explained by evapotranspiration than by precipitation indices. According to their results the amount of evapotranspiration during the rice flowering period and during the harvesting period affects credit risk of lenders in Madagascar.

However, methods based on weather station data are limited in less developed countries due to the scarcity of weather station networks and availability of long-term continuous time series of weather data (Meroni, Kayitakire, & Brown, 2013). Especially, the performance of precipitation-based index insurance is affected by the distance to the next weather station due to the spatial variability of precipitation. With an increasing distance to the next weather station, the correlation between crop yield and precipitation indices usually decreases (Gommes & Göbel, 2013; Norton, Turvey, & Osgood, 2012).

Besides station-based weather data, remotely-sensed data can be used to derive underlying indices for index insurance. An important advantage of remotely-sensed data is that the accuracy does not depend on the density and distribution of weather stations since the data is provided nearly in real time and is globally available (Makaudze & Miranda, 2010). The literature mainly focuses on the use of the Normalized Difference Vegetation Index (NDVI) with mixed results. The NDVI determines the density and vigor of green biomass and is thus an indicator for the health of vegetation. The NDVI is primarily used as an index for biomass assessment in forage insurance (Chantarat, Mude, Barrett, & Carter, 2013; Leblois et al., 2014; Miranda & Farrin, 2012). Thus, the NDVI is also utilized as an index for index-based livestock insurance, insuring for example pastoralists in Africa against drought induced livestock mortality (Chantarat et al., 2013). In a case study in Zimbabwe, Makaudze and Miranda (2010) designed an index insurance based on an NDVI time series as well as maize and cotton yields. They found that NDVI-based index insurance exhibits less basis risk for farmers than the commonly used precipitation-based index insurance. Testing the applicability of the NDVI as an underlying index for index insurance, Turvey and Mclaurin (2012) find that the NDVI is not a suitable index without site specific calibrations.

The vegetation health indices, developed by Kogan (1990), including the Vegetation Condition Index (VCI), the Temperature Condition Index (TCI) and the Vegetation Health Index (VHI) consider site specific calibrations. In recent years, vegetation health indices have been mainly used in the agricultural context for yield prediction and drought monitoring. The results of various case studies have proven that the VCI and TCI reveal high correlations with crop yield for different climate conditions in countries like Kazakhstan (Bokusheva, Kogan, Vitkovskaya, Conradt, & Batyrbayeva, 2016), the Midwestern United States (Salazar, Kogan, & Roytman, 2007), Russia (Kogan et al., 2016), South Africa (Unganai & Kogan, 1998) and India (Rahman, Roytman, Krakauer, Nizamuddin, & Goldberg, 2009). Since the VHI is a composite index combining the VCI and the TCI, the correlation between the VHI and crop yield has been found to be even higher (Kogan et al., 2016). With regards to the cultivation of rice, Rahman et al. (2009) find the correlation between rice yield and the VHI to be as high as 0.83, explaining 62 % of the rice yield variance in Bangladesh. Bokusheva et al. (2016) consider the VCI and TCI as indices for index insurance in a case study in Kazakhstan. The authors designed VCI- and TCI-based index insurance for insuring winter wheat yield in Kazakhstan, reducing the yield risk by up to 70 % (Bokusheva et al., 2016). Möllmann, Buchholz, and Musshoff (2018) find the vegetation-based index insurance outperforms weather station based contracts for most of the analyzed German sample farms.

However, there is no empirical evidence on the potential of vegetation-based index insurance for risk analysis of risk aggregators such as agricultural lenders to date. Therefore, the objective of this paper is to fill this gap by analyzing the explanatory power of remotely-sensed vegetation health indices for credit risk of a commercial Microfinance Institution (MFI) in Madagascar. In doing so, we evaluate whether it is reasonable for a meso-level institution like the investigated MFI to hedge their credit risk with vegetation-based index insurance. Madagascar is well-suited for this study as its economic and social structure represents the typical conditions in African countries (Minten, Randrianarison, & Swinnen, 2009). The study area is predominately characterized by the cultivation of rice (Minten et al., 2009). Hence, agricultural income in the study region heavily depends on rice yields and farmers take up loans to finance inputs needed for the cultivation of rice. Farmers' loan repayment performance thus depends on rice yields whose variability can be explained to a great extent by the vegetation health indices (Rahman et al., 2009). Consequently, we expect that the vegetation health indices can contribute to explaining credit risk of the MFI's agricultural loan portfolio. To investigate this, we first analyze whether the MFI's credit risk correlates with the vegetation health indices during the critical growth phases of the rice production cycle and determine the periods of highest correlation. Secondly, we include the VCI, TCI and VHI for the determined periods jointly with loan- and borrower-specific variables as covariates in sequential logit model (SLM). Finally, in order to assess if the explanatory power of the remotely-sensed indices changes depending on lenders' exposure to credit risk, we apply Quantile Regression (QR).

The remainder of the paper is structured as follows. Section 2 reviews the relevant literature on hedging credit risk with index insurance. In section 3, we present the MFI and the loan data set. Section 4 presents the remotely-sensed data used and the calculation of the vegetation health indices. In section 5, we describe the methodological approach. The results are shown and discussed in section 6, while section 7 draws out the conclusion of our results.

2 Index insurance and credit risk

Since agriculture is the prime source of income for smallholder farmers in less developed countries, weather risks are assumed to be a main driver of the risk in rural lending (Farrin & Miranda, 2015; Giné & Yang, 2009; Miranda & Gonzalez-Vega, 2010). Extreme weather events such as droughts, floods or freezes are considered to further increase in the future due to climate change (Mirza, 2003). Extreme weather events can decrease the profitability of agricultural production and consequently smallholder farmers' ability to repay their loans in due time is jeopardized (Binswanger & Rosenzweig, 1986). Collier, Katchova, and Skees (2011) investigate the effects of El Niño-related catastrophic flooding on loan portfolio performance of an MFI in Peru. They find that El Niño increased the number of loans that were restructured from their original terms and those that were not repaid in due time. In an analysis of the effect of volcanic eruptions on loan default rates of lenders in Ecuador, Berg and Schrader (2012) find that the probability of loan default increases after high volcanic activity. Czura and Klonner (2010) find a statistically significant increase in the interest rate charged to agricultural borrowers of 5.3 percent on average in response to the effects of the 2004 Indian Ocean Tsunami. Hence, uninsured extreme weather-related risks can limit the evolution of agricultural credit markets in less developed countries (Barnett et al., 2008; Carter et al., 2011; Farrin & Miranda, 2015; Giné & Yang, 2009; Mahul & Skees, 2007).

In light of this issue, index insurance is widely discussed as a promising risk management tool (Makaudze & Miranda, 2010; Miranda & Farrin, 2012; Miranda & Gonzalez-Vega, 2010). However, take-up of index insurance, especially micro-level index insurance designed to be held by individual farmers, remains low in less developed countries (Carter et al., 2017; Platteau et al., 2017). Reasons for the low take-up of micro-level index insurance are complications on the demand-side and supply-side. On the demand-side, the low take-up of micro-level index insurance is often explained by borrower characteristics such as lack of trust in the insurance provider or a lack of understanding of the insurance product. The costs of micro-level index insurance and the contract design are mentioned as supply-side complications (Carter et al., 2017; Platteau et al., 2017). Upfront premium payments may be problematic for liquidity-constrained smallholder farmers. Clarke (2016) argues that due to high premiums for unsubsidized index insurance, expected utility maximizers are often better off not purchasing insurance. The reason for this argument is the high level of basis risk in micro-level index insurance products due to idiosyncratic production losses that are not captured by the weather index, for example losses related to variable growing conditions (Miranda & Farrin, 2012). Karlan, Osei, Osei-Akoto, and Udry (2014) find that demand for index insurance decreases with increasing basis risk.

Several studies investigate the effect of offering loan and index insurance contracts together (Carter et al., 2011; Giné & Yang, 2009; Miranda & Farrin, 2012; Miranda & Gonzalez-Vega, 2010). In a field experiment in Malawi, Giné and Yang (2009) offer loans to farmers to purchase high-yielding seeds. A stand-alone loan contract with a limited-liability was offered to one treatment group, while the other group was required to purchase micro-level index insurance at actuarially fair rates. The results show that take-up of the loan contract bundled with micro-level index insurance was 13 percentage points lower. The authors explain the unexpected results by the fact that the farmers were already insured by the limited liability making additionally insurance excessive. Utilizing a simulation model, Miranda and Gonzalez-Vega (2010) find that the mandatory purchase of micro-level index insurance with realistic insurance premiums increases farmers' loan default rates. The necessity to pay the insurance premium for the mandatory index insurance results in a disincentive for the farmer to repay the loan. However, they find that it is more beneficial if the MFI directly buys index insurance to hedge the weather-related covariate loan portfolio risk (Miranda & Gonzalez-Vega, 2010). Index insurance that focuses on insuring agricultural intermediaries, such as MFIs, is called meso-level index insurance (Carter et al., 2017; Farrin & Miranda, 2015; Miranda & Gonzalez-Vega, 2010).

Meso-level index insurance avoids some of the complications associated with micro-level products. Since loan portfolios of MFIs include loans of many farmers who are geographically dispersed, the idiosyncratic production risk that is borne by farmers can be diversified. Covariate risks due to extreme weather events affecting the whole geographical scope of the MFI remain. Hence, meso-level index insurance should hedge cash flow shortfalls due to weather related loan defaults more closely than farmers' individual cash flow shortfalls. This implies that basis risk of meso-level index insurance contracts is less pronounced compared to their micro-level counterparts (Carter et al., 2017; Miranda & Farrin, 2012; Miranda & Gonzalez-Vega, 2010). Moreover, increasing contract sizes lead to relatively reduced transaction costs compared to micro-level products since meso-level index insurance works more effectively and efficiently due to the reduced basis risk (Collier & Skees, 2012). Moreover, facing lower default rates enables lenders to reduce interest rates and consequently farmers will demand more credit. Thus, risk-rationed farmers are crowded in, whereas previously, they were excluded from the financial market (Carter et al., 2011; Collier & Skees, 2012; Platteau et al., 2017). Due to a greater financial analytical capacity, MFIs should be better able to understand index insurance. This also allows for more complex index insurance designs (Miranda & Farrin, 2012). Altogether, the benefits of index insurance are likely to be greater for an MFI than for individual smallholder farmers (Skees & Barnett, 2006).

3 Study area and loan data

The climate in the study area is characterized by a rainy season from November to April and a dry season from May to October. According to the literature, Madagascar exhibits a high vulnerability to climate change leading to a higher frequency of extreme weather events such as droughts and cyclones (Nematchoua, Ricciardi, Orosa, & Buratti, 2018). The rice production cycle varies throughout the area under investigation. However, it can be roughly described as follows: the major rice production cycle starts with the beginning of the rainy season in November. Seeds are pre-germinated and the 30-40 day-old seedlings are transplanted into prepared rice plots at the end of November. After transplanting, the vegetative growth phase including tillering and leafing begins which lasts until mid/end of February. The following reproductive growth phase including panicle initiation and heading lasts until the mid of April. Finally, after ripening, harvest takes place at the end of May/beginning of June (Vergara, 1991).

Our investigation focuses on the credit risk of the agricultural loan portfolio of the AccèsBanque Madagascar (ABM) in the central highlands of Madagascar. ABM is a commercial microfinance bank with a core target group of micro-, small- and medium-sized enterprises (ABM, 2016). The lending situation in Madagascar is characterized by expensive and limited access, especially in rural areas. Consequently only a small fraction, about 3 percent, of the rural population has a bank account (Kerer et al., 2016). In our study, we focus on agricultural clients of the ABM that predominately cultivate rice in monoculture. These farmers take up loans for rice cultivation. The agricultural loan portfolio is managed by specially trained managers and loan officers in 9 out of the 29 branch offices (ABM, 2016). Every branch office serves farmers within a 30-kilometer radius which is equivalent to a one-hour motorbike drive. In order to obtain an agricultural loan, the share of agricultural income needs to be more than 50 percent of clients' total income (Kerer et al., 2016).

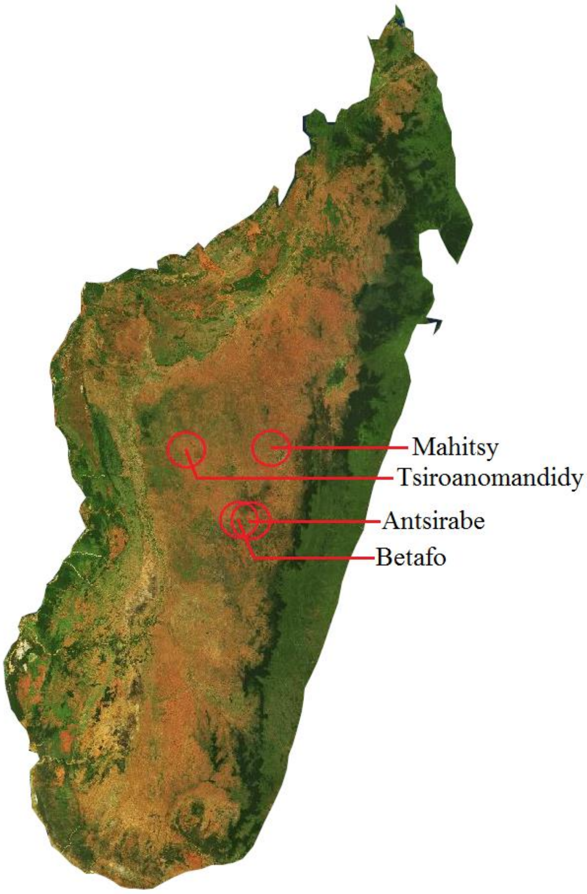

Figure 1. Location of the branch offices and radius of served agricultural clients.
Source: Digital Globe (2018).

The loan data used for our analysis is extracted from the management information system of the ABM. Of the 9 branches offering loans to agricultural borrowers, we consider the data of 4 branches in our analysis. The 4 branches are located in the central highlands of Madagascar (Figure 1). We have selected these branches since each has disbursed at least around 1,000 loans. Additionally, we analyze the aggregated bank level, including the data of all 4 branches. In total our analysis includes 5,313 agricultural loans which were granted between November 2010 and February 2015 (month of data extraction). Loans disbursed between April and June are excluded since these are unlikely to have been used for rice cultivation. The dataset is cleaned to correct for data input errors.

The dataset includes information on loan and socio-demographic characteristics of the borrowing farmers (Table 1). Moreover, it provides information about the ABM's credit risk.

According to the Basel II regulations, the credit risk of the ABM is given by the portfolio at risk (PAR), a common risk measure in the banking practice indicating the share of the loan portfolio that is overdue by a certain number of days. An announcement is required when a loan installment is overdue by 90 days or more (Navarrete & Navajas, 2006). In contrast to the common banking sector, the PAR in microfinance is based on a 30 day overdue basis (Schreiner, 2000). Three different PAR measures are considered by the ABM. From the PAR measures, we derive credit risk indicators (CRI). The CRIs are dummy variables that take on the value of one if at least one payment falls into the respective PAR category. The PAR measures and the CRI are defined as follows:

(1) PAR-0 (CRI-0): all loan installments were paid in due time

(2) PAR-1: number of the installment payments overdue by one to 14 days
CRI-1: at least one installment payment is overdue by one to 14 days

(3) PAR-15: number of the installment payments overdue by 15 to 29 days
CRI-15: at least one installment payment is overdue by 15 to 29 days

(4) PAR-30: number of the installment payments overdue by at least 30 days
CRI-30: at least one installment payment is overdue by at least 30 days.

Table 1. Descriptive statistics of dependent and independent variables[a)].

	Unit	Mean	SD	Min.	Max.
Credit risk indicators (CRI)					
CRI 0	1/0[b)]	0.43			
CRI 1	1/0[b)]	0.46			
CRI 15	1/0[b)]	0.04			
CRI 30	1/0[b)]	0.05			
Loan characteristics					
Loan volume	Thd. MGA[d]	1,360,961	1,480,940	150,000	15,500,000
Maturity	Month	12.45	3.35	1.00	35.00
Repeat client	1/0[b)]	0.44			
Collateral	1/0[b)]	0.08			
Socio-demograhic characteristics					
Gender (male)	1/0[b)]	0.72			
Age	Years	43.41	11.10	20.00	84.00
Married	1/0[b)]	0.89			
Family members	Number	4.78	1.94	0.00	16.00

[a)] n = 5,134. [b)] Dummy coded variable: 1 = yes, 0 = no. [c)] Thd. MGA = Thousand Madagascar Ariary.
Source: Author’s calculation.

Table 1 displays the means of the CRI. Around 43 % of the loans were repaid in due time. The share of loans that were overdue by at least one day (CRI-1) is, at 46 %, comparatively high, while it drops considerably for CRI-15 and CRI-30.

4 Calculation of the vegetation health indices

The remotely-sensed data used for this study was derived from the Advanced Very High Resolution Radiometer (AVHRR) satellite dataset provided by the National Oceanic and Atmospheric Administration (NOAA/STAR, 1981). Statistically smoothed NDVI and Brightness Temperature (BT) 7-day composites with a resolution of 4 x 4 km for the period of 2009-2015 are taken from this dataset. By means of pre- and post-launch calibration coefficients, the data is converted to reflectance.

The NDVI is calculated from the visible (VIS) and near-infrared (NIR) spectral bands observed by the AVHRR sensors according to the formula $NDVI = (NIR - VIS)/(VIS + NIR)$. Healthy vegetation is characterized by little reflection of VIS and strong reflection of NIR. The green leaf pigment chlorophyll absorbs VIS for use in photosynthesis, while other leaf structures reflect NIR. If vegetation is under stress, for example water stress, the NDVI becomes smaller due to a higher reflectance of VIS and a lower reflectance of NIR. Thus, higher NDVI values correspond to healthier vegetation. The BT is a measurement of the land and vegetation surface temperature. Due to reduced transpiration, the temperature of the vegetation surface under water stress is higher than for unstressed, healthy vegetation (Kogan, 1995; Kogan et al., 2016).

The VCI is derived from the normalization of NDVI values based on the maximum and minimum NDVI values for a specific region and is expressed as (Kogan, 1990; Kogan et al., 2016; Unganai & Kogan, 1998):

$$VCI_w = 100 \cdot \frac{NDVI_w - NDVI_{min}}{NDVI_{max} - NDVI_{min}}, \qquad (1)$$

where $NDVI_w$ is the smoothed 7-day NDVI for week w, and $NDVI_{max}$ and $NDVI_{min}$ are the absolute maximum and minimum values calculated for each pixel over the entire observation period 2009-2015. The VCI was proposed as a means to separate the spatial variability of the NDVI into the effect of weather and the effect of geographical resources like soil type, vegetation type, geographic region and climate zone (Kogan, 1990). The principle of the VCI is based on the assumption that the vegetation reaches a maximum biomass with optimal weather conditions because such weather leads to an efficient use of geographic resources. In contrast, if the weather conditions are unfavorable due to water stress, the plant's ability to benefit from the geographic resources is reduced. The calculation of the VCI includes the minimum and maximum values over the whole observation period in order to relate weekly measurements to the worst and the best possible weather conditions. In doing so, it is possible to quantify the potential of the specific region given by its geographic resources. The VCI has been found to better capture the precipitation dynamics than the NDVI and still provides a description of land cover as well as spatial and temporal vegetation change. Producing values between 0 and 100, the VCI indicates how far vegetation development is from the minimum and maximum of the geographical potential in the region of interest (Kogan, 1995; Unganai & Kogan, 1998).

The formula for the TCI is similar to the VCI except for a change to address the fact that a high BT reflects unfavorable conditions due to high vegetation surface temperatures, while a low BT indicates more favorable conditions. Consequently, the TCI is calculated as follows (Kogan et al., 2016; Unganai & Kogan, 1998):

$$TCI_w = 100 \cdot \frac{BT_{max} - BT_w}{BT_{max} - BT_{min}}, \tag{2}$$

where BT_w is the smoothed 7-day BT for week w, and BT_{max} and BT_{min} are the absolute maximum and minimum values calculated for each pixel over the entire observation period. The values of the TCI also range from 0 to 100. Corresponding to the VCI, values close to 0 indicate thermal vegetation stress and values close to 100 indicate that the maximum benefit has been derived from the given geographical resources of the specific region (Kogan et al., 2016).

Combining both indices results in the weighted additive composite called VHI, which is expressed as (Kogan et al., 2016; Unganai & Kogan, 1998):

$$VHI_w = a \cdot VCI_w + (1 - a) \cdot TCI_w, \tag{3}$$

where a is the weighting coefficient quantifying the contribution of VCI and TCI to the VHI. According to Kogan et al. (2016), equal weights of VCI and TCI can be assumed ($a = 0.5$) because the relative contribution of moisture and temperature to vegetation health is currently not known.

Since the loan officers service farmers within a radius of 30 km around the branch office, we consider all NDVI and BT pixels within this area that are cultivated with rice. In order to identify the pixels covering arable land cultivated with rice, we use pansharpened imagery provided by Digital Globe (2018). The number of relevant pixels range from 113 for the branch located in Betafo to 172 for the branch located in Antsirabe (Figure 1). The number of relevant pixels at the aggregated bank level equals the sum of all branch level pixels and amounts to 581 pixels. For each branch and the aggregated bank level, we calculate the minimum and maximum BT and NDVI values. By calculating the average NDVI and BT values over all relevant pixels, we derive weekly values of these indices for each branch and at the aggregated bank level. The VCI, TCI and VHI are calculated according to equations (1) to (3). The weekly vegetation health indices are then converted to monthly indices, since ABM disburses loans on a monthly basis. Figure 2 shows the monthly values of the VCI, TCI and VHI at the aggregated bank level for years 2014 and 2015. The TCI reaches a peak during the vegetative phase of the growth cycle of rice in Madagascar. The VCI and VHI reach a peak during the reproductive phase. Hence, the curving of the vegetation health indices corresponds to the most critical growth phases for rice yield formation.

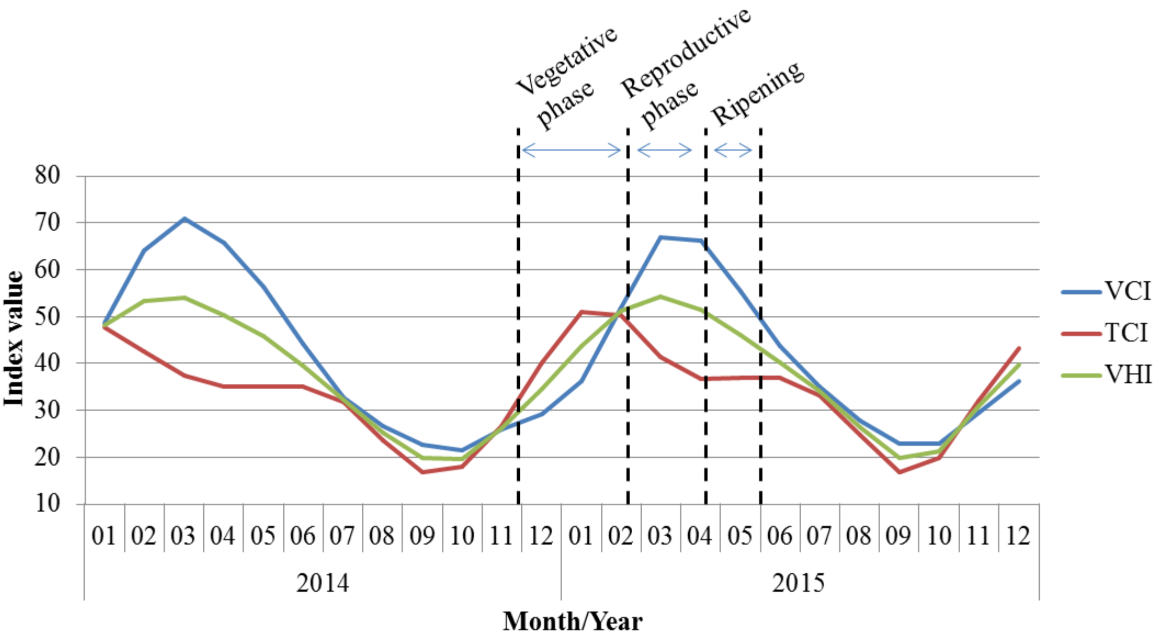

Figure 2. Monthly values of the VCI, TCI and VHI for 2014 and 2015 at the aggregated bank level; dashed lines indicate the beginning and end of the rice growth phases in Madagascar.

The monthly vegetation health indices are averaged over certain accumulation periods. The accumulation periods are determined by identifying the period with the highest Spearman correlation coefficient between the respective index and the CRI. We assume that the farmers take up loans to finance inputs needed for the cultivation of rice. These loans are repaid with the income generated by selling the rice harvested in the previous season. Hence, the credit risk of ABM's agricultural loan portfolio depends on its clients' rice yields from the previous season. To account for this, we calculate the Spearman correlation coefficients between the vegetation health indices representing the vegetation conditions of the previous season and the CRI for the loans taken up to finance the inputs for the following season[1]. The indices $I_{t-1,b}$ representing the accumulated VCI, TCI or VHI correspond to the average values of the monthly VCI, TCI and VHI (Jewson & Brix 2005):

$$I_{t-1,b} = \frac{1}{x}\sum_{m=1}^{x} I_m^{t-1,b}, \tag{4}$$

where $I_m^{t-1,b}$ indicates the respective vegetation health index for month m, in season t-1 and for branch or aggregated bank level b, while x indicates the length of the accumulation period in months.

5 Econometric approach

In the following, the methodological approach to estimate the influence of the VCI, TCI and VHI on ABM's credit risk is explained. Therefore, SLMs are estimated. Since credit risk does not solely depend on farmers' rice yield (Onyeagocha et al., 2012; Shu-Teng, Zariyawati, Suraya-Hanim, & Annuar, 2015), we additionally include the loan- and sociodemographic characteristics of the loan data in the SLM. The SLM is a special type of logistic regression model with categorical dependent variables $y_i \epsilon \{i = 1, \dots, d\}$ for loan i and a number of d different categories. In our model, the credit risk indicators CRI-0, CRI-1, CRI-15, CRI-30 refer to the d = 4 different categories. The CRI can only be met successively - meaning that farmers of category CRI-30, have to go through categories CRI-1 and CRI-15 first before reaching CRI-30. The first category ($y_i = 1$) includes all loans for which every installment is paid in due time (CRI-0). Accordingly, the second ($y_i = 2$), third ($y_i = 3$), and forth ($y_i = 4$) categories include the loans associated with CRI-1, CRI-15 and CRI-30, respectively. The SLM allows for the successive movement from one response category to the next (Hausman & McFadden, 1984; Tutz, 2005; Wong & Mason, 1985). For each consecutive category, a separate logistic regression on the subsample is estimated. Every transition to the next category is a binary decision. The SLM estimates the influence of the independent variables on the conditional chance of the transition from category r to category r+1 (Tutz, 2005; Wong & Mason, 1985). The conditional chance for the transition into category r+1 can be generally determined by (Tutz, 2005):

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[1] Using a logistic regression model, the correlation analysis is checked for robustness. We include the respective vegetation health index accumulated over a certain period and the loan- and sociodemographic variables in separate models for each CRI. The results are not displayed.

$$P(y_i = r|x_i) = F\big(\beta_{0,r-1} + x_i'\beta\big), \qquad r = 1, \dots, d, \tag{5}$$

where $P(y_i = r|x_i)$ is the conditional chance that y_i takes on the value r given the considered independent variables x_i. F is a logistic function and $x_i'\beta$ can be defined as follows (Tutz, 2005):

$$x_i'\beta = I_{t-1,b} \times \beta_1 + c_{i,t} \times \beta_2 + s_{i,t} \times \beta_3 + v_{i,t}, \quad I = VCI, TCI, VHI, \tag{6}$$

where $I_{t-1,b}$ is the respective vegetation health index in season *t*-1 for branch or aggregated bank level *b*; $c_{i,t}$ represents a vector describing the loan characteristics; $s_{i,t}$ is a vector describing the socio-demographic characteristics of the farmers. We consider the loan and socio-demographic characteristics shown in Table 1. The variable $v_{i,t}$ is a normally distributed error term with a variance and mean of zero which is independently and identically distributed for all *i* and *t*.

Estimated coefficients are transformed into odds ratios since the coefficients in log-odds units are difficult to interpret. The odds ratios represent the ratio of the odds for an outcome to occur to the odds for an outcome not to occur. A coefficient equal to zero results in an odds ratio of 1, which indicates no difference in the odds. An odds ratio greater than 1 indicates that an outcome is more likely to occur than not to occur. If the odds ratio is smaller than 1 an outcome is more likely not to occur than to occur.

Finally, to allow the influence of the vegetation health indices and the additionally considered loan and socio-demographic variables to differ along the distribution of PAR-1, we rely on Quantile Regression (QR) (Koenker & Bassett, 1978). We have chosen the PAR-1 as the dependent variable for this purpose since the CRI-1 as defined above is a dummy-coded variable (Table 1). PAR-1 has been chosen over PAR-15 and PAR-30 since the sample size of loans sharply decreases with increasing risk indicators. The QR considers specific parts of the conditional distribution of PAR-1 and allows for the estimation of the influence of the independent variables respectively at lower, median and upper quantiles of the distribution. Since PAR-1 is count data, its distribution function is not continuous. Consequently, the quantiles are not continuous and cannot be modelled as a continuous function of the regressors (Winkelmann, 2006). This problem can be overcome by jittering PAR-1, as shown by Machado and Silva (2005). In doing so, the count data is artificially smoothed by adding uniformly distributed noise to PAR-1. The QR model that is estimated refers to:

$$q_r(y_{PAR}) = I_{t,b} \times \beta_1(r) + c_{i,t} \times \beta_2(r) + s_{i,t} \times \beta_3(r) + v_{i,t}, \quad I = VCI, TCI, VHI, \; \forall r \in [0,1] \tag{7}$$

where $q_r(y_{PAR})$ is the *r*th conditional quantile of the PAR-1 distribution. Considering the previous notation, $\beta_1(r)$, $\beta_2(r)$ and $\beta_3(r)$ are the estimated coefficients at different quantiles *r* of the conditional distribution of PAR-1.

6 Influence of the vegetation health indices on credit risk at different aggregation levels

6.1 Correlation coefficients and period of highest correlation

Summary statistics of the Spearman correlation coefficients between the accumulated vegetation health indices for season *t*-1 and the credit risk indicators for the following season *t* (CRI-1, CRI-15, CRI-30) are presented in Table 2. As findings of Kogan et al. (2016) indicate, the VHI shows the highest performance in explaining crop yields compared to the VCI and TCI. Looking at the means in Table 2, we find slightly higher correlation coefficients between the vegetation health indices and the credit risk indicators which are indirectly connected to the rice yields of the borrowers. On average, the highest correlation coefficients are estimated for the VHI (Table 2). The magnitude of the correlation coefficients decreases considerably with every transition to the next credit risk indicator. This decreasing influence of the vegetation health indices in higher credit risk categories can also be observed in the estimation results of the SLMs.

For the VCI and VHI, the period of highest Spearman correlation is found to range from February to April across all branches and the aggregated bank level (Table 3, 4). These months refer to the end of the vegetative growth phase and cover the reproductive growth phase of rice in the study area. The period of highest correlation calculated for the TCI occurs slightly earlier and therefore mainly refers to the vegetative growth phase in rice cultivation (Table 3, 4). Hence, the periods of highest Spearman correlation occur during the most critical growth phases for rice yield formation (Vergara, 1991). This finding confirms that the farmers use the income generated from selling the harvested rice from the previous year to repay their loans.

6.2 Sequential Logit Model results

The results of each SLM expressed as odds ratios for the aggregated bank level are shown in Table 3. We estimate one SLM for each vegetation health index and select the same loan and socio-demographic characteristics for each SLM. The odds ratios for the vegetation health indices are all statistically significant and the values are smaller than 1 – meaning that the conditional chance for the transition into the next credit risk category is reduced with every

Table 2 . Spearman correlation coefficients between the vegetation health indices and the CRI for the period of highest correlation at the branch and aggregated bank level[a].

Index	VCI			TCI			VHI		
	CRI-1	CRI-15	CRI-30	CRI-1	CRI-15	CRI-30	CRI-1	CRI-15	CRI-30
Antsirabe	-0.52***	-0.25***	-0.16***	-0.51***	-0.25***	-0.16**	-0.52***	-0.25***	-0.16**
Mahitsy	-0.29***	-0.12***	-0.06*	-0.46***	-0.20***	-0.14**	-0.49***	-0.21***	-0.15**
Betafo	-0.43***	-0.25***	-0.17**	-0.44***	-0.25***	-0.20***	-0.44***	-0.25***	-0.20***
Tsiroanomandidy	-0.49***	-0.29***	-0.20***	-0.40***	-0.21***	-0.17**	-0.40***	-0.21***	-0.17**
Aggregated bank level	-0.47***	-0.23***	-0.17**	-0.47***	-0.23***	-0.17**	-0.47***	-0.23***	-0.17**
Mean	-0.44	-0.23	-0.15	-0.46	-0.23	-0.17	-0.47	-0.24	-0.18

Notes: [a] * p≤0.05, ** p≤0.01, *** p≤0.001.
Source: Author's calculation.

Table 3. Estimation results of the SLM for credit risk indicated by CRI-1, CRI-15, CRI-30 at the aggregated bank level; displayed as odds ratios[a].

	Unit	VCI (February-March)			TCI (December)			VHI (March)		
		Transition 1[b]	Transition 2[c]	Transition 3[d]	Transition 1[b]	Transition 2[c]	Transition 3[d]	Transition 1[b]	Transition 2[c]	Transition 3[d]
Vegetation index	0-100	0.561***	0.718***	0.893*	0.764***	0.829***	0.945*	0.472***	0.781***	0.914*
Loan characteristics										
Loan volume	Thd. MAG[e]	1.000	1.000***	1.000*	1.000	1.000***	1.000*	1.000	1.000***	1.000*
Maturity	Month	1.108***	1.039**	1.011	1.103***	1.035**	1.009	1.106***	1.024*	1.010
Repeat client	1/0[f]	1.231***	0.991	1.033	1.194***	0.968	1.027	1.093	0.978	1.030
Collateral	1/0 [f]	0.370***	0.607*	0.753	0.367***	0.603	0.749	0.369***	0.606*	0.752
Socio-demographic characteristics										
Gender (male)	1/0 [f]	0.885*	1.001	1.081	0.881*	1.002	1.082	0.883*	1.002	1.082
Age	Years	0.984***	0.988***	0.975***	0.985***	0.988***	0.975***	0.985***	0.988**	0.975***
Married	1/0 [f]	0.989	0.969	0.885	1.010	0.985	0.890	1.002	0.981	0.889
Family members	Number	1.045***	0.984	1.011	1.041***	0.981	1.009	1.043*	0.982	1.010
log-likelihood		-4,990			-4,952			-4,960		

Notes: [a]n = 5,313; * p≤0.05, ** p≤0.01, *** p≤0.001. [b] (CRI-1+CRI-15+CRI-30) vs CRI-0;[c] (CRI-15+CRI-30) vs CRI-1;[d] CRI-30 vs CRI-15
[e]Thd. MGA = thousand Madagascar Ariary. [f]Dummy coded variable: 1=yes, 0=no.
Source: Author's calculation.

additional unit of the respective vegetation health index. The highest reduction of the conditional chance that at least one installment payment is overdue by one day (passing from CRI-0 to CRI-1) is estimated for the VHI. An increase in the VHI calculated for March by one unit reduces the conditional chance of passing from CRI-0 to CRI-1 by 52.8 %. A one unit increase in the VCI averaged over the months February to March reduces the conditional chance to move from CRI-0 to CRI-1 by 43.9 %. The TCI in December has the smallest effect on credit risk. Every unit increase in the TCI decreases the conditional chance to move from CRI-0 to CRI-1 by only 23.6 %. The conditional chance to move from CRI-1 to CRI-15 is decreased by 28.2 % per index point of the VCI, by 17.1 % per index point of the TCI and by 21.9 % per index point of the VHI. For the third transition (CRI-15 to CRI-30), we estimate the smallest reduction in the conditional chance. The conditional chance is reduced by 10.7 %, 5.5 % and 8.6 % for the VCI, TCI and VHI, respectively.

A recent study by Negenborn et al. (2018) finds that evapotranspiration and precipitation indices calculated from weather station data can also explain credit risk of agricultural loan portfolios. However, for the highest aggregation level, they find the credit risk reducing potential of the evapotranspiration index to range from only 0.3 % to 3.7 % per index point. The credit risk reduction potential of the precipitation index is found to be even smaller, ranging from 0.2 % to 0.3 % per index point. The great difference between the results using vegetation health indices and weather station indices might refer to a higher basis risk inherent in weather station based indices (Möllmann et al., 2018).

Furthermore, Table 3 shows the results for the loan- and sociodemographic variables. The loan maturity statistically significantly increases the conditional chance that a loan passes the first and second transitions. Being a repeat client statistically significantly increases the conditional chance to pass the first transition for the models including the VCI and TCI. This effect becomes statistically insignificant for the model including the VHI. While the loan volume has no effect, pledging collateral statistically significantly decreases the chance of passing the first and second transition. Furthermore, we observe statistically significant effects for gender, age and the number of family members. While most of these findings are in line with the literature, the effects of the loan volume and of being a repeat client contradict them (Onyeagocha et al., 2012; Shu-Teng et al., 2015). Shu-Teng et al. (2015) find that a higher loan volume corresponds to a higher repayment performance. Loan officers more frequently visit clients with larger loan amounts. Repeat clients are found to have a higher repayment performance due to a higher work experience (Onyeagocha et al., 2012). The fact that we find the opposite

Table 4. Estimation results of the SLM for credit risk indicated by CRI-1, CRI-15, CRI-30 at the branch level; displayed are only the odds ratios for the vegetation health indices[a)].

	VCI			TCI			VHI		
Branch	Transition 1[b)]	Transition 2[c)]	Transition 3[d)]	Transition 1[b)]	Transition 2[c)]	Transition 3[d)]	Transition 1[b)]	Transition 2[c)]	Transition 3[d)]
Antsirabe	0.851***	0.929***	1.010	0.751***	0.827***	0.984	0.604***	0.790***	1.006
n=1,834	log-likelihood: -1,789			log-likelihood: -1,717			log-likelihood: -1,792		
	Period: March			Period: December-January			Period: February-March		
Mahitsy	0.825***	0.951	1.010	0.756***	0.885***	1.026	0.601***	0.881***	1.017
n=996	log-likelihood: -979			log-likelihood: -616			log-likelihood: -942		
	Period: February-March			Period: December-February			Period: February		
Betafo	0.498***	0.603***	1.450	0.743***	0.790***	0.883*	0.229***	0.388***	0.591*
n=1,477	log-likelihood: -1,427			log-likelihood: -1,412			log-likelihood: -1,439		
	Period: February-May			Period: November-January			Period: February		
Tsiroanomandidy	0.406***	0.293***	0.929	0.826***	0.886***	0.824***	0.756***	0.944	0.702**
n=1,006	log-likelihood: -839			log-likelihood: -895			log-likelihood: -936		
	Period: March			Period: January			Period: February-April		

Notes: [a)]* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$. [b)] (CRI-1+CRI-15+CRI-30) vs CRI-0; [c)] (CRI-15+CRI-30) vs CRI-1; [d)] CRI-30 vs CRI-15.
Source: Author's calculation.

might be related to a less strict loan assessment by the loan officers who might think that they know their clients well.

The odds ratios of passing each transition for the vegetation health indices at the individual branch level are shown in Table 4. The SLMs include the same loan- and sociodemographic variables as in the analysis for the aggregated bank level. For reasons of clarity, we omit results for loan and socio-demographic characteristics. Complete model results can be found in appendix A (Table A1-A4). The decrease in the conditional chance to move from CRI-0 to CRI-1 is statistically significant for all indices at all branch offices. Except for the VCI at the branch office in Mahtisy and VHI at the branch office in Tsiroanomandidy, the odds ratios are also statistically significant for the second transition from CRI-1 to CRI-15. Considering the last transition, we observe statistically significant results for the branch offices Betafo and Tsiroanomandidy for the indices TCI and VHI.

As already observed for the aggregated bank level, the VHI leads to the highest decrease in the conditional chance to pass the first and second transitions for the branch offices in Antsirabe, Mahitsy and Betafo. However, we find the VCI to result in the highest reduction of the conditional chance to pass the first and second transitions in Tsiroanomandidy. This might be related to the fact that compared to the other branch offices, Tsiroanomandidy is located in the West of Madagascar (Figure 1). While for Antsirabe and Mahitsy, the TCI outperforms the VCI, we find a higher explanatory power of the VCI in Betafo (Table 4). A varying performance of the different vegetation health indices across different regions has already been found by Bokusheva et al. (2016) and Möllmann et al. (2018). This variability might be related to the quality of the remotely-sensed data, local species (Kogan, Gitelson, Zakarin, Spivak, & Lebed, 2003) or the precision of identifying the areas that were cultivated with rice by the clients of the ABM. With regard to passing the first transition, the highest reduction of the conditional chance is achieved by the VHI in Betafo, with 77.1 % per additional index point. The highest reduction of the conditional chance of moving from CRI-1 to CRI-15 is estimated for the VCI in Tsiroanomandidy, with 70.7 % per additional index point. We estimate the highest reduction in the conditional chance of passing from CRI-15 to CRI-30 for the VHI in Betafo, with 40.9 % per additional index point. Regarding the loan- and socio-demographic characteristics, we only find minor differences in the results between the branch and aggregated bank level.

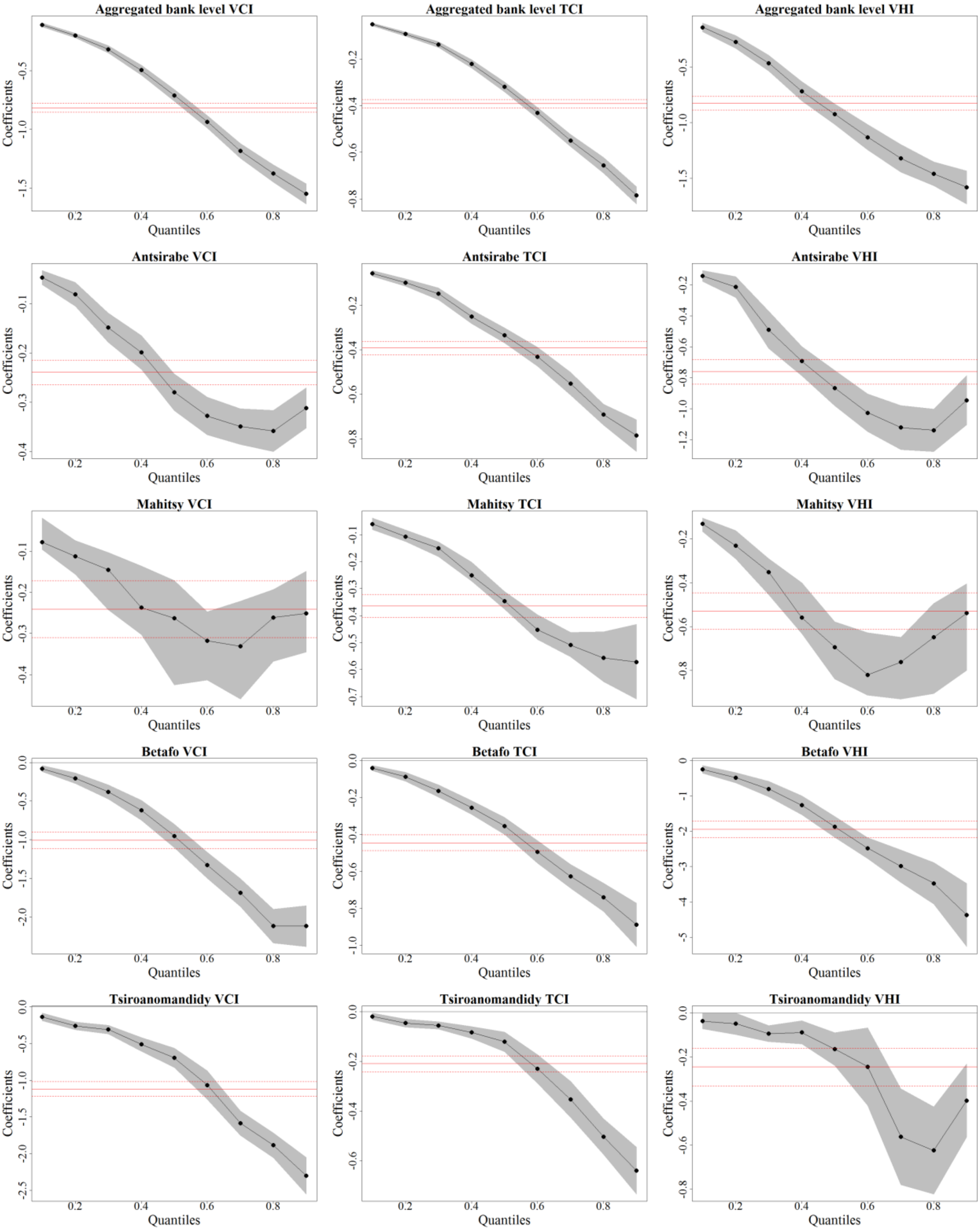

Figure 3. Estimation results of quantile regressions for PAR 1; only results for the vegetation health indices at the aggregated bank level and at the branch level are provided; shaded areas depict 95 % confidence bands; red lines depict ordinary least squares estimates and their 95 % confidence bands.

6.3 Quantile regression results

To go beyond averages, we run quantile regressions with the dependent variable being the number of installments that are overdue between one and 14 days (PAR-1). Figure 3 shows the estimated coefficients for the three vegetation health indices at the aggregated bank and the individual branch level. Single coefficient values and their respective significance levels can be found in appendix B. In the quantile regressions, we consider the same loan- and sociodemographic variables as in the SLMs. For reasons of clarity, the results for the loan- and sociodemographic variables are omitted. The influence of the vegetation health indices on the PAR-1 increases from the lower to the upper quantiles of the conditional distribution. At the aggregated bank level for the 0.1 quantile, we have estimated coefficients of -0.11, -0.05 and -0.13 for the VCI, TCI and VHI, respectively. These coefficients continuously increase to reach coefficients of -1.15, -0.78 and -1.57 at the 0.9 quantile for the VCI, TCI and VHI, respectively. Thus, the explanatory power of the vegetation health indices increases with increasing credit risk.

This also holds true for the individual branch level (Figure 3). However, we find the explanatory power of the VCI and VHI for Antsirabe and Mahitsy and the VHI for Tsiroanomandidy to revert and slightly decrease in the upper quantiles of the conditional distribution of PAR-1 (Figure 3).

All in all, the QR results are in line with the SLM results. At the aggregated bank level, the reduction of the conditional chance of passing the first transition is highest for the VHI followed by the VCI and TCI (Table 3). The same order can be observed for the influence of the vegetation-indices along the distribution of PAR-1 (Figure 3). As estimated by the SLM, we also find the VHI to be the best performing index for Antsirabe, Mahitsy and Betafo using quantile regressions. In line with the SLMs, the VCI is again the best performing index for Tsiroanomandidy (Table 4, Figure 3). On the one hand, our results stress that the performance of the different indices varies not only across the branch offices but also across different quantiles. On the other hand, our results indicate that vegetation health indices can explain a considerable amount of ABM’s credit risk, especially as their explanatory power increases in the upper part of the distribution of PAR-1.

7 Conclusion

Smallholder farmers’ vulnerability to adverse weather events is one of the main impediments to a sufficient credit supply in less developed countries such as Madagascar. Smallholder farmers’ access to credit is, among other factors, crucial for productivity and output growth. Insuring the agricultural loan portfolios of MFIs could help to compensate for lacking installment payments in years with severe weather conditions and thus, is considered to accelerate agricultural lending.

This paper investigates the explanatory power of three remotely-sensed vegetation health indices for credit risk at the aggregated bank level and at the individual branch level for an MFI in Madagascar. Using SLMs and quantile regression, we estimated the influence of VCI, TCI and VHI as additional explanatory variables on the loan repayment performance of smallholder rice farmers. According to the literature, the vegetation health indices exhibit high correlations with cereal yields and especially rice yield (Rahman et al., 2009). Since the investigated MFI disburses loans to farmers who mainly generate their income from selling their harvested rice, the loan repayment performance is very likely dependent on rice yields. Hence, remotely-sensed indices need to sufficiently explain rice yield variability in order to exhibit a high correlation with the credit risk of the agricultural loan portfolio of the MFI.

According to our results, the highest correlation between the indices VCI and VHI and the considered credit risk indicators is found at the end of the vegetative and during the reproductive growth phases of rice. The period of highest correlation estimated for the TCI occurs slightly earlier and mainly corresponds to the vegetative growth phase in rice cultivation. These growth phases are the most critical in rice yield formation (Vergara, 1991). This confirms that the farmers use the income generated from selling the harvested rice to repay their loans. Results of the SLMs reveal that the VHI most adequately explains the MFI’s credit risk. However, we find the VCI to outperform the VHI for the branch office that is located in the western part of the study area. A varying performance of vegetation health indices across regions is in line with the literature (Bokusheva et al., 2016; Kogan et al., 2003; Möllmann et al., 2018) and could be related to the quality of the remotely-sensed data, local species (Kogan et al., 2003) or the precision of identifying the areas that were cultivated with rice by the clients of the ABM. Results of the quantile regressions show that the explanatory power is higher in the upper quantiles of the distribution of the number of installments that were overdue between one and 14 days.

Compared to studies considering meteorological indices derived from weather station data, our results show that vegetation health indices exhibit a considerably higher explanatory power of MFIs’ credit risk (Negenborn et al., 2018). A key advantage of remotely-sensed vegetation health indices is that their accuracy does not depend on the density and distribution of weather stations which are often limited in less developed countries (Meroni et al., 2013). Hence, our results suggest that vegetation health indices could outperform meteorological indices for use in index-based insurances due to a potentially lower basis risk associated with vegetation-based index insurance.

Due to the high performance of vegetation health indices and the fact that idiosyncratic risks can be diversified in meso-level insurance products, vegetation-based index insurance might be particularly valuable for MFIs to hedge the credit risk related to the variability of borrowers' rice yields. Such a meso-level index insurance product might operate as follows: the MFI buys blanket insurance for all new borrowers with rice cultivation as their main source of income. If the considered vegetation health index falls below a specified strike level the insurance pays the lender an indemnity, and the borrower is relieved of his debt obligation by the same amount as the indemnity payment (Shee & Turvey, 2012). Facing lower default rates, the MFI can reduce interest rates which could enhance farmers' access to credit (Carter et al., 2011; Collier & Skees, 2012; Platteau et al., 2017).

Based on our findings, we suggest future research focus on designing vegetation-based index insurance products at the meso-level. Due to the pronounced importance of rice cultivation for smallholder farmers in our study area, crop-specific meso-level index insurance products seem valuable. To further increase precision, future research could focus on utilizing remotely-sensed data with a higher resolution. In doing so, further insights into the reasons for the varying performance of the vegetation health indices across the regions could be gained. Additionally, the applicability of alternative indices like the Fraction of Photosynthetically Active Radiation (FAPAR), as suggested by Meroni et al. (2013), could be considered. Although the availability of data on the repayment performance of smallholders is limited, we encourage generalization of our findings using longer time series of loan datasets.

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Appendix A

Table A1. Estimation results of the SLM for credit risk indicated by CRI-1, CRI-15, CRI-30 for the branch located in Antsirabe; displayed as odds ratios[a].

		VCI			TCI			VHI		
	Unit	Transition 1[b]	Transition 2[c]	Transition 3[d]	Transition 1[b]	Transition 2[c]	Transition 3[d]	Transition 1[b]	Transition 2[c]	Transition 3[d]
Vegetation-index		0.851***	0.929***	1.010	0.751***	0.827***	0.984	0.604***	0.790***	1.006
Loan characteristics										
Loan volume	Thd.MAG[e]	1.000	1.000***	1.000	1.000	1.000***	1.000	1.000	1.000***	1.000
Maturity	Month	1.080***	0.994	1.033	1.059***	0.977	1.033	1.082***	0.995	1.034
Repeat client	1/0[f]	0.942	0.714*	0.789	1.006	0.755	0.807	1.031	0.761	0.789
Collateral	1/0[f]	0.380***	0.690	1.103	0.377***	0.723	1.158	0.394***	0.714	1.107
Socio-demographic characteristics										
Geschlecht	1/0[f]	0.807**	0.905	0.933	0.842	0.902	0.944	0.840	0.916	0.944
Alter	Years	0.987***	0.984**	0.966**	0.983***	0.982**	0.966**	0.984***	0.982**	0.966**
Married	1/0[f]	1.055	1.403	2.074	0.908	1.359	2.111	0.969	1.383	2.089
Family members	Number	1.007	0.973	0.936	1.040	0.974	0.935	1.026	0.974	0.937
log-likelihood		-1,789			-1,717			-1,792		

Notes: [a]n = 1,834; * p≤0.05, ** p≤0.01, *** p≤0.001. [b] (CRI-1+CRI-15+CRI-30) vs CRI-0;[c] (CRI-15+CRI-30) vs CRI-1;[d] CRI-30 vs CRI-15
[e]Thd. MGA = thousand Madagascar Ariary. [f]Dummy coded variable: 1=yes, 0=no.
Source: Author’s calculation.

Table A2. Estimation results of the SLM for credit risk indicated by CRI-1, CRI-15, CRI-30 for the branch located in Mahitsy; displayed as odds ratios a).

		VCI			TCI			VHI		
	Unit	Transition 1 b)	Transition 2 c)	Transition 3 d)	Transition 1 b)	Transition 2 c)	Transition 3 d)	Transition 1 b)	Transition 2 c)	Transition 3 d)
Vegetation-index		0.825***	0.951	1.010	0.756***	0.885***	1.026	0.601***	0.881***	1.017
Loan characteristics										
Loan volume	Thd.MAG e)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Maturity	Month	1.078**	1.082	1.017	1.071*	1.069	1.016	1.094**	1.079	1.014
Repeat client	1/0 f)	0.780*	0.756	1.520	0.941	0.789	1.509	0.940	0.789	1.509
Collateral	1/0 f)	0.135***	0.444	0.638	0.200***	0.533	0.782	0.186***	0.488	0.563
Socio-demographic characteristics										
Geschlecht	1/0 f)	1.195	0.672	0.612	1.150	0.651*	0.608	1.171	0.659*	0.610
Alter	Years	0.985***	0.992	0.978	0.983**	0.992	0.978	0.984**	0.992	0.978
Married	1/0 f)	0.739	0.386***	0.546	0.895	0.416***	0.516	0.845	0.401***	0.535
Family members	Number	1.094**	1.033	0.983	1.068*	1.024	0.990	1.082**	1.031	0.985
log-likelihood		-979			-916			-942		

Notes: a) n = 996; results displayed as odds ratios; * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$. b) (CRI-1+CRI-15+CRI-30) vs CRI-0; c) (CRI-15+CRI-30) vs CRI-1; d) CRI-30 vs CRI-15
e) Thd. MGA = thousand Madagascar Ariary. f) Dummy coded variable: 1=yes, 0=no.
Source: Author’s calculation.

Table A3. Estimation results of the SLM for credit risk indicated by CRI-1, CRI-15, CRI-30 for the branch located in Betafo; displayed as odds ratios a).

		VCI			TCI			VHI		
	Unit	Transition 1 b)	Transition 2 c)	Transition 3 d)	Transition 1 b)	Transition 2 c)	Transition 3 d)	Transition 1 b)	Transition 2 c)	Transition 3 d)
Vegetation-index		0.498***	0.603***	1.450	0.743***	0.790***	0.883*	0.229***	0.388***	0.591*
Loan characteristics										
Loan volume	Thd.MAG e)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.130
Maturity	Month	1.096***	1.064***	0.943	1.142***	1.135***	0.964	1.118***	0.967***	1.248
Repeat client	1/0 f)	0.991	0.810	0.810	1.313**	1.031	0.897	1.248*	1.035	0.906
Collateral	1/0 f)	0.256***	0.324*	1.034	0.308***	0.399	0.793	0.285***	0.388	0.769
Socio-demographic characteristics										
Geschlecht	1/0 f)	0.748*	1.184	1.254	0.766*	1.191	1.292	0.770*	1.182	1.309
Alter	Years	0.986***	0.985*	0.953***	0.985***	0.986*	0.957***	0.984**	0.986*	0.956**
Married	1/0 f)	0.961	0.972	0.579	1.114	1.157	0.495	1.047	1.088	0.478
Family members	Number	1.040	1.011	0.978	1.042	1.007	0.986	1.045	1.012	0.986
log-likelihood		-1,427			-1,412			-1,439		

Notes: a)n = 1,477; * p≤0.05, ** p≤0.01, *** p≤0.001. b) (CRI-1+CRI-15+CRI-30) vs CRI-0; c) (CRI-15+CRI-30) vs CRI-1; d) CRI-30 vs CRI-15
e)Thd. MGA = thousand Madagascar Ariary. f)Dummy coded variable: 1=yes, 0=no.
Source: Author’s calculation.

Table A4. Estimation results of the SLM for credit risk indicated by CRI-1, CRI-15, CRI-30 for the branch located in Tsiroanomandidy; displayed as odds ratios[a].

		VCI			TCI			VHI		
	Unit	Transition 1[b]	Transition 2[c]	Transition 3[d]	Transition 1[b]	Transition 2[c]	Transition 3[d]	Transition 1[b]	Transition 2[c]	Transition 3[d]
Vegetation-index		0.406***	0.293***	0.929	0.826***	0.886***	0.824***	0.756***	0.944	0.702**
Loan characteristics										
Loan volume	Thd.MAG[e]	1.000	1.000**	1.000	1.000	1.000**	1.000	1.000	1.000**	1.000
Maturity	Month	1.061**	0.867***	1.198*	1.075**	0.917*	1.261**	1.069**	0.908**	1.277**
Repeat client	1/0[f]	1,149**	1.743**	0.554	1,471**	1.623	0.703	1.178	1.177	0.681
Collateral	1/0[f]	0,476**	0.694	0.229	0,461***	0.639	0.000	0.397***	0.558	0.748
Socio-demographic characteristics										
Geschlecht	1/0[f]	0.951	1.437	1.013	0.892	1.305	1.008	0.915	1.345	1.018
Alter	Years	0.990	0.998	1.006	0.993	1.004	1.005	0.996	1.006	1.007
Married	1/0[f]	1.081	0.798	1.763	1.148	0.786	1.667	1.167	0.763	1.613
Family members	Number	1.043	0,899**	1.216	1.037	0.889*	1.202	1.043	0.902*	1.198
log-likelihood		-839			-895			-936		

Notes: [a]n = 1,006; * p≤0.05, ** p≤0.01, *** p≤0.001. [b] (CRI-1+CRI-15+CRI-30) vs CRI-0;[c] (CRI-15+CRI-30) vs CRI-1;[d] CRI-30 vs CRI-15
[e]Thd. MGA = thousand Madagascar Ariary. [f]Dummy coded variable: 1=yes, 0=no.
Source: Author’s calculation.

Appendix B

Table B1. Estimation results of quantile regressions for PAR 1; displayed are only the results for the vegetation health indices at the aggregated bank level and at the branch level.

Quantiles		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
VCI	Aggregated bank level	-0.105***	-0.200***	-0.312***	-0.458***	-0.681***	-0.955***	-1.202***	-1.351***	-1.576***
	Antsirabe	-0.038**	-0.078***	-0.138***	-0.207***	-0.285***	-0.341***	-0.345***	-0.364***	-0.310***
	Mahitsy	-0.019	-0.089	-0.155**	-0.188***	-0.262***	-0.356***	-0.316***	-0.259***	-0.227***
	Betafo	-0.105*	-0.245***	-0.441***	-0.656***	-1.037***	-1.346***	-1.694***	-1.998***	-2.191***
	Tsiroanomandidy	-0.116**	-0.280***	-0.334***	-0.466***	-0.721***	-1.092***	-1.577***	-1.922***	-2.330***
TCI	Aggregated bank level	-0.048***	-0.090***	-0.137***	-0.205***	-0.306***	-0.432***	-0.557***	-0.651***	-0.791***
	Antsirabe	-0.056***	-0.096***	-0.164***	-0.242***	-0.333***	-0.453***	-0.578***	-0.665***	-0.839***
	Mahitsy	-0.049*	-0.099***	-0.155***	-0.240***	-0.338***	-0.434***	-0.521***	-0.576***	-0.586***
	Betafo	-0.055**	-0.104***	-0.160***	-0.254***	-0.372***	-0.497***	-0.644***	-0.769***	-0.891***
	Tsiroanomandidy	-0.029**	-0.049***	-0.059***	-0.084***	-0.122***	-0.233***	-0.361***	-0.480***	-0.646***
VHI	Aggregated bank level	-0.156***	-0.287***	-0.455***	-0.674***	-0.943***	-1.179***	-1.353***	-1.465***	-1.610***
	Antsirabe	-0.129**	-0.252***	-0.446***	-0.668***	-0.866***	-1.062***	-1.095***	-1.139***	-0.975***
	Mahitsy	-0.106*	-0.206***	-0.303***	-0.457***	-0.663***	-0.779***	-0.797***	-0.713***	-0.510***
	Betafo	-0.308**	-0.580***	-0.934***	-1.320***	-1.987***	-2.501***	-2.851***	-3.607***	-4.463***
	Tsiroanomandidy	-0.056*	-0.077*	-0.097**	-0.115**	-0.192***	-0.351***	-0.531***	-0.592***	-0.384*

Notes: $^{a)}$ * p≤0.05, ** p≤0.01, *** p≤0.001.
Source: Author's calculation.

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Die Wurzeln der **Fakultät für Agrarwissenschaften** reichen in das 19. Jahrhundert zurück. Mit Ausgang des Wintersemesters 1951/52 wurde sie als siebente Fakultät an der Georgia-Augusta-Universität durch Ausgliederung bereits existierender landwirtschaftlicher Disziplinen aus der Mathematisch-Naturwissenschaftlichen Fakultät etabliert.

1969/70 wurde durch Zusammenschluss mehrerer bis dahin selbständiger Institute das **Institut für Agrarökonomie** gegründet. Im Jahr 2006 wurden das Institut für Agrarökonomie und das Institut für Rurale Entwicklung zum heutigen **Department für Agrarökonomie und Rurale Entwicklung** zusammengeführt.

Das Department für Agrarökonomie und Rurale Entwicklung besteht aus insgesamt neun Lehrstühlen zu den folgenden Themenschwerpunkten:

- Agrarpolitik
- Betriebswirtschaftslehre des Agribusiness
- Internationale Agrarökonomie
- Landwirtschaftliche Betriebslehre
- Landwirtschaftliche Marktlehre
- Marketing für Lebensmittel und Agrarprodukte
- Soziologie Ländlicher Räume
- Umwelt- und Ressourcenökonomik
- Welternährung und rurale Entwicklung

In der Lehre ist das Department für Agrarökonomie und Rurale Entwicklung führend für die Studienrichtung Wirtschafts- und Sozialwissenschaften des Landbaus sowie maßgeblich eingebunden in die Studienrichtungen Agribusiness und Ressourcenmanagement. Das Forschungsspektrum des Departments ist breit gefächert. Schwerpunkte liegen sowohl in der Grundlagenforschung als auch in angewandten Forschungsbereichen. Das Department bildet heute eine schlagkräftige Einheit mit international beachteten Forschungsleistungen.

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