Rice flows across regions in Madagascar

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Abstract

This paper examines rice trade flows within and across regions in Madagascar, based on data of unique rice sales collected in 22 major markets in Madagascar in 2012 and 2013. We find that intra-regional trade accounts for a large fraction of the overall rice trade. We then focus on factors that may affect inter-regional transactions, such as market status (i.e. deficit or surplus), geographical proximity and seasonality (harvest vs. non-harvest and rainy vs. dry). We find that rice flows mainly from surplus to deficit regions and within regions that are geographically proximate. Seasonal factors have a generally negligible impact on rice flow.

Key words: trade flow; origin; destination; rice; Madagascar

1. Introduction

It is well recognised that the degree of commodity market integration has a significant impact on food (in)security. Well-integrated markets provide a mechanism that helps move food efficiently from surplus to deficit areas and minimises the adverse effects of region-specific shocks, such as crop failure (Zant 2012). In developing countries like Madagascar, where food insecurity remains a serious issue and where commodity markets are not well integrated (e.g. Moser *et al*. 2009), it is critical to understand how and when major staple foods are traded.

This paper examines the trade flows of rice in Madagascar. We focused on rice, which is the country's main staple food and the most tradable product among all agricultural commodities (Minten & Dorosh 2006). We examined trade flows because spatial equilibrium models indicate that they are the driving force behind market integration.[1] Specifically, we first mapped the origin and destination of the main categories of rice sold in the country and described the flow patterns throughout the year. Second, we identified the determinants of inter-regional trade, focusing on market status (i.e. deficit or surplus),

[1] More recent studies (e.g. Ihle *et al*. 2010; Stephens *et al*. 2012) also indicate that markets can be integrated without direct trade flows.

geographical proximity and seasonality. We relied on a novel dataset that recorded the origin of rice sold by retailers in 22 major markets in Madagascar each week between June 2012 and May 2013.

The main findings are as follows. First, a large fraction of the rice trade is conducted within regions, meaning that rice sold in the market is mainly produced within the same region. Second, rice-deficit markets tend to import rice and experience inflow more frequently than surplus regions do. Surplus regions, in contrast, are more likely to export rice than are deficit regions. Third, distance has a strongly negative association with inter-regional flow. For example, inflows are 4.5 times higher for adjacent market-origin pairs than for non-adjacent pairs. Fourth, in terms of seasonality, the probability of inflows does not decline in the rainy season. Moreover, no clear pattern shows that the probability of inflows increases over time after the main harvest.

This paper contributes to the literature on trade flow in Sub-Saharan Africa. Previous studies have suggested the importance of commodity flow from surplus to deficit areas for stabilising food availability and prices (e.g. Haggblade *et al*. 2008). It has also been found that seasons affect the direction of trade between two regions over the course of a year because of differences in harvest times between regions (e.g. Minten 1999). However, to the best of our knowledge, no study has measured the degree of trade within and between surplus and deficit regions or the impact of distance and seasons have on inter-regional flow in a Sub-Saharan African country. Such knowledge is required to form a comprehensive picture of commodity flows and to better understand the market environment, thus enabling a clearer interpretation of the results from spatial price transmission analyses (Fackler & Goodwin 2001). Flow analysis can complement the spatial integration approach by clarifying the geography of markets and describing how markets are spatially distributed and linked, and how and when commodities such as rice are traded (FEWS NET 2009). Thus, this paper also contributes broadly to market integration studies.

The paper is organised as follows. Section 2 describes the study's hypotheses, survey and data. Section 3 explains what we observed in terms of rice flows across regions and seasons. Sections 4 and 5 discuss the observed patterns of inter-regional flow and the study's limitations respectively. Finally, concluding remarks are offered in Section 6.

2. Method and data

In this section we first present our hypotheses about the determinants of inter-regional trade; second, we describe the survey from which the main dataset in the paper is derived; and lastly, we explain key conceptual terms and categories used in the analysis.

2.1 Hypotheses

We hypothesise that rice flow can be explained by two main factors: (1) rice self-sufficiency and (2) proximity between regions. Regions with a rice shortage (deficit regions) may need to import rice from other regions, whereas regions with rice surpluses can supply rice to other regions. Origin–destination proximity might also play an important role in trade: given transportation costs, rice flows are expected to occur more frequently between proximate regions.

Seasonality could influence these two factors. A region may be rice-sufficient immediately after the harvest season but might run out of stock over time and become rice-deficit in the off-harvest period. Thus, the extent of self-sufficiency changes within a year. Similarly, whereas the physical distance between two regions may be fixed, the travel time might change and become longer in the rainy season than in the dry season, which is likely to be magnified by poor road quality (i.e. unpaved roads) and heavier rainfall.

To examine the observed pattern of rice flow based on our hypotheses, we estimate variants of the following basic equation:

$$y_{ijt} = \beta_0 + \beta_1 \text{DEFICIT}_i + \beta_2 \text{SURPLUS}_j + \beta_3 \text{DIST}_{ij} + \beta_4 \text{SEASON}_{it} + \beta_5 \text{SEASON}_{jt} + \delta_t + \varepsilon_{ijt}, \quad (1)$$

where y_{ijt} is a dummy variable equal to one if rice flows from origin region j to market (destination) region i in week t; DEFICIT_i is an indicator that destination region i has a rice deficit; SURPLUS_i is an indicator that origin region j has a rice surplus; DIST_{ij} is a variable that captures the proximity of the two regions; SEASON_{it} and SEASON_{jt} are vectors of seasonal variables in destination i and origin j;[2] δ_t represents week fixed effects; and ε_{ijt} is an error term. We expect β_2 to be negative (indicating that rice-surplus regions tend to experience lower inflow frequency) and β_3 to be negative (indicating that long-distance pairs are less likely to trade). The estimation result is presented in Section 4.2.

2.2 Survey

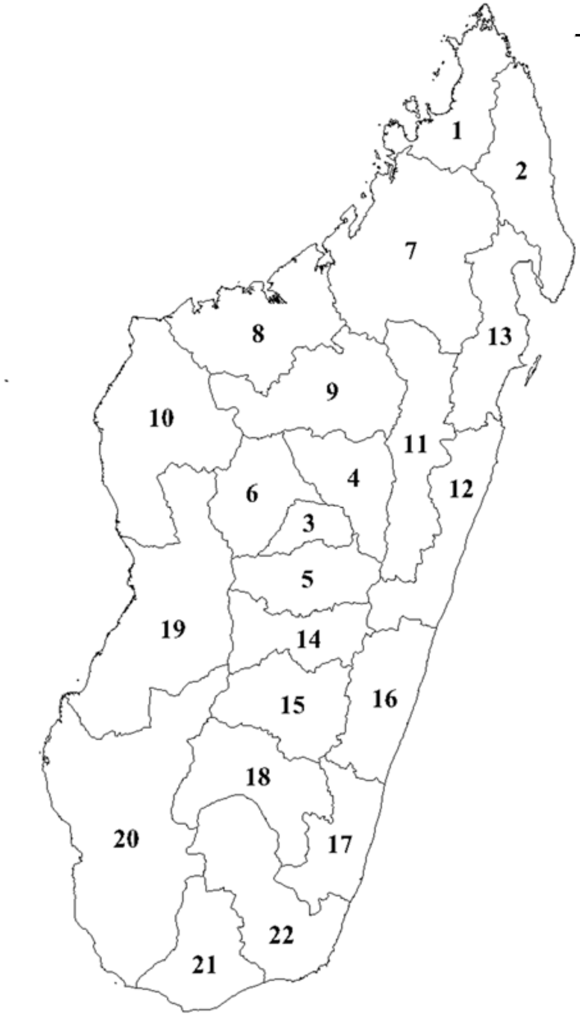
This study draws mainly from a dataset containing domestic rice flow information. Data was collected on a weekly basis over a 52-week period, starting from the main harvest month, June 2012, until May 2013. Trained enumerators (officials from Madagascar's National Statistics Institute, or INSTAT) conducted face-to-face interviews using a structured questionnaire with five randomly selected retailers[3] in the largest rice market in each of Madagascar's 22 regional[4] capital cities (see Figure 1). Interviews were conducted on the given market day[5] of the assigned market in each city, and questions about all the types of rice sold, including name, price and sale quantity, were asked. Moreover, for each type of rice the retailer was selling, we asked him/her which region the rice was produced in, allowing us to learn the origin of all the rice sold across the country.

[2] We included different seasonal variables for the destination and origin to control for seasonal variations in each region separately because they may affect inter-regional transactions differently. For example, if the origin is in the harvest season, the probability of inflow from that region would be high, whereas if the destination is in the harvest season, its probability would be low because local rice is more easily available.

[3] Rice retailers are rice traders who sell primarily to consumers and from a fixed stall. The survey excluded occasional traders, such as farmers who come to the market only on a market day to sell rice on the streets around the market.

[4] The region is the highest administrative unit in Madagascar, followed by the district. There are 111 districts.

[5] The market day is the best day of the week to capture all types of rice sold in the market. For cities that have no specific market day, the survey was conducted at various times, except on Sundays (when the market is deserted), but on the same day every week.



Code	Region Name	Region Capital
1	Diana	Antsiranana I
2	Sava	Sambava
3	Itasy	Miarinarivo
4	Analamanga	Antananarivo Renivohitra
5	Vakinankaratra	Antsirabe I
6	Bongolava	Tsiroanomandidy
7	Sofia	Antsohihy
8	Boeny	Mahajanga I
9	Betsiboka	Maevatanana
10	Melaky	Maintirano
11	Alaotra mangoro	Ambatondrazaka
12	Atsinanana	Toamasina I
13	Analanjirofo	Fenoarivo Atsinanana
14	Amoron'i mania	Ambositra
15	Haute Matsiatra	Fianarantsoa I
16	Vatovavy Fitovinany	Manakara
17	Atsimo Atsinanana	Farafangana
18	Ihorombe	Ihosy
19	Menabe	Morondava
20	Atsimo Andrefana	Toliara I
21	Androy	Ambovombe
22	Anosy	Taolagnaro

Figure 1: Regions of Madagascar
Source: Authors (Data from Madagascar's Rice Observatory 2015)

2.3 Data

We categorise our data into four types: rice category, flow, regional characteristics and distance. Table 1 reports all the data used in our analysis and the sources of the data.

Table 1: Data types and sources

Data	***Source***
Rice category	Our survey data
Rice flow	Our survey data
Regional characteristics:	
- Population per region	FEWS NET (2013b)
- Breakdown of population by rural and urban areas	INSTAT (2010)
- Consumption per capita	INSTAT (2005)
- Rice production	Ministry of Agriculture and Rural Development (2014)
- Rainy/dry season	Ministry of Agriculture, Livestock and Fishery (2007), FEWS NET (2013a)
- Harvest season	Ministry of Agriculture, Livestock and Fishery (2007), FEWS NET (2013a)
Distance	FTM (1994)

Source: Authors
Note: Ministry of Agriculture and Rural Development and Ministry of Agriculture, Livestock and Fishery are the same ministry, but its name changed over time.

2.3.1 Rice category

Our survey data classify rice into five categories, meaning groups of rice types: *vary gasy*, *tsipala*, *makalioka*, import, and unknown.[6] In the following analyses, we focus on the movements of the three main groups of domestic rice: *vary gasy*, *tsipala* and *makalioka*. We conduct separate analyses of each category because they may face different demand functions.[7] *Vary gasy* is a generic term that refers to any locally produced rice other than *tsipala* and *makalioka*. *Tsipala* and *makalioka* are two different kinds of rice with unique appearances that can be easily distinguished in the market. *Makalioka* is considered high-grade rice and, when processed cleanly, it is the most expensive rice in Madagascar.

2.3.2 Rice flow

A commodity flow analysis examines origins and destinations. Origins are rice-producing regions, whereas destinations are the consuming markets (i.e. the regional capitals in which the survey was conducted). We defined origins and destinations at the regional level. The terms "origin" and "destination" are used interchangeably with "producing region" and "consuming region (or market)" respectively. Using our weekly survey data, we consider that a directed "flow"[8] occurs from origin j to destination (market) i if the rice sold by our sampled retailer in market i was produced in region j. In the following analyses, we also consider intra-regional flows – trades that occur within a region (i.e. where the origin and destination are the same [$i = j$]).

[6] As a comparison, Madagascar's Rice Observatory classifies rice sold in the market into four groups: *vary gasy*, *tsipala*, *makalioka*, and imported.
[7] See Sakurai *et al*. (2015) for more discussion of regional rice preferences.
[8] The terms "link" and "trade" are used depending on the context. "Flow" implies a direction, whereas "link" and "trade" do not.

2.3.3 Regional characteristics

We examined the annual rice-sufficiency status and seasonality (i.e. harvest and rainy season) for each region. Table A1 in the Appendix shows how we calculated rice sufficiency status by region. We estimated total rice production and consumption in each region[9] and determined whether the district is rice-surplus (i.e. when rice production exceeds consumption). We identified 10 deficit regions and 12 surplus regions. The largest deficit region was *Analamanga*, which is the most highly populated region and is where Madagascar's capital city is located. By contrast, *Vakinankaratra*, the second most highly populated region, is the largest surplus region.[10] Table A2 in the Appendix describes the seasonal variables: rainy season and harvest season. These are dummy variables obtained at the month level, and we attribute that information to the week level.

2.3.4 Distance

For all 231 $(= \mathrm{C}(22,2) = (22 \times 21)/2)$ (non-directed) combinations of market pairs that could form an inter-regional flow, we constructed a dataset of road distances (km) between the capitals of two regions and a dummy variable equal to 1 if the two regions are adjacent. Table A3 in the Appendix shows the distance between a market pair and describes their proximity.

2.3.5 Weeks elapsed since the last main harvest

Given that rice self-sufficiency might change over time, we constructed a variable measuring elapsed weeks since the last main harvest using information on the main harvest month for each region (presented in Table A2). For example, if the main harvest season (defined by month) occurs during April and May, this variable takes a value of 1 for the first week of June, a value of 2 for the second week of June, a value of 31 for the last week of December, and of 32 for the first week of January. The end of the count is 43, for the last week of March. This variable is defined only for weeks during the non-main harvest months.

3. Description of the flows

In this section, we identify our main observations regarding the actual rice flow across regions and seasons in Madagascar.

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[9] The Ministry of Agriculture estimates production per region every year. Because official data were not available, for consumption we rely on the results of estimations of per capita consumption during the 2005 household survey conducted by INSTAT. Although the data are not perfectly accurate, they are the most reliable available data on rice consumption in Madagascar. This household survey shows that average rice consumption differs across regions and between urban and rural areas. Therefore, to obtain data on total consumption by region, we added urban and rural consumption for each region. Then, to obtain data on urban and rural consumption for each region, we multiplied the per capita consumption in urban and rural areas by the urban and rural population respectively.

[10] The surplus status of the region could be explained partly by the fact that the population consumes less rice than other regions in the central part of the country. Rice consumption per capita averages 87.6 kg per year and 77 kg per year in urban and rural areas respectively. Lower rice consumption is compensated for by a greater consumption of potatoes and cassava, which *Vakinankaratra* produces abundantly (Ministry of Agriculture, Livestock and Fishery 2007).

3.1 Observations

Our basic unit of observation is the combination of origin–destination–week–category. With 22 regions, 52 weeks and three rice categories, the maximum number of possible observations is 75 504 (including intra-regional flows).

Out of 75 504 possible observations, 2 428 transactions (3.1%) occurred during the observation period. Table 2 shows the composition of flows by rice category, origin and destination. Concerning rice categories, 1 398 observations out of 2 428 (57.6%) are of *vary gasy*, 649 (26.7%) are of *tsipala*, and 381 (15.7%) are of *makalioka*. Regarding region of origin, Alaotra Mangoro represents the largest number of observations for flow origin by far and accounts for 16.8% of the total observations, followed by Sofia and Bongolava, with 8.4% and 7.6% respectively. While Alaotra Mangoro is the main producer of *makalioka*, Sofia and Bongolava are large producers of *tsipala* rice. Regarding destination, Analamanga, Vakinankaratra, and Vatovavy Fitovinany are the main rice inflow regions, representing 10%, 9%, and 7% of the total observations respectively. These three regions are the first-, second- and fifth-largest regions in terms of population respectively.

Figure 2 shows the number of observations by week for each rice category. Rice transactions are implemented throughout the year at almost the same frequency, regardless of whether it is the harvest season or not. This pattern is found to be similar across all three rice categories.

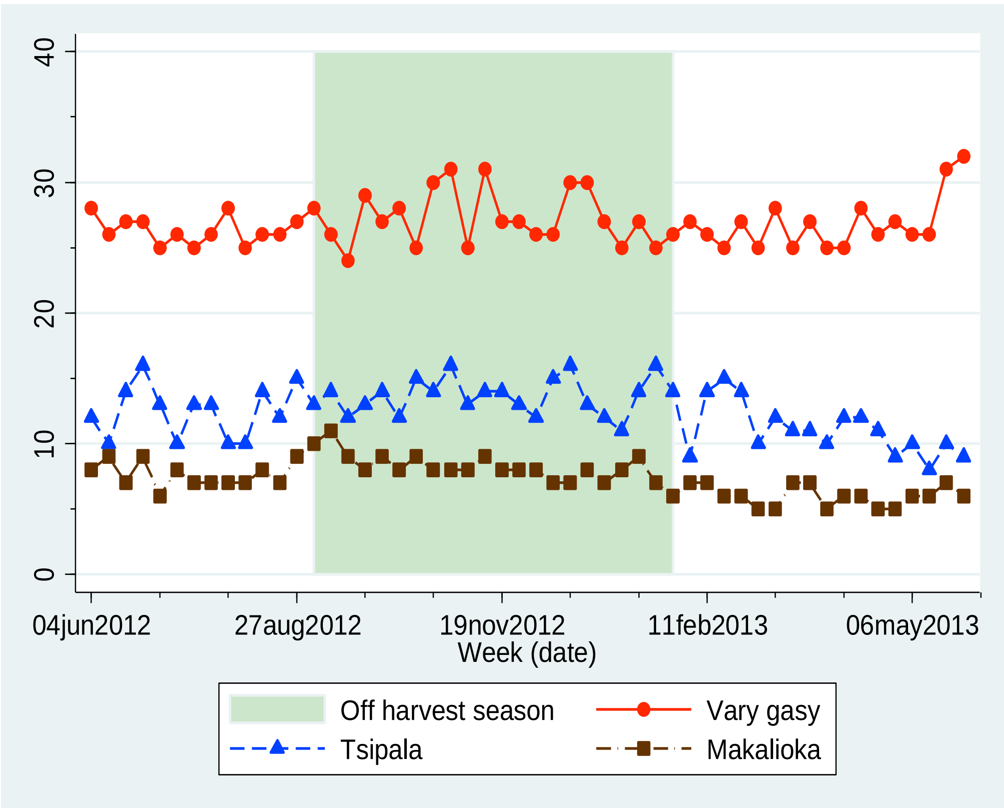


Figure 2: Number of inflows by week and rice category

Source: Authors (Data for inflows by rice category from the Madagascar Retailer Survey 2012-2013; data showing off-harvest months are from FEWS NET (2013a) and the Ministry of Agriculture, Livestock and Fishery (2007)).

Note: Figure 2 depicts the number of observed inflows. Intra-regional flows are included. Unit of observation is market–origin–week–category (N = 75 504).

Table 2: Number of flows

	As market (region of consumption)					As origin of production				
	Vary gasy	Tsipala	Makalioka	Total	%	Vary gasy	Tsipala	Makalioka	Total	%
Analamanga	111	69	54	234	*9.6%*	6	1	0	7	*0.3%*
Vakinankaratra	104	53	53	210	*8.6%*	55	50	1	106	*4.4%*
Itasy	53	28	0	81	*3.3%*	109	35	2	146	*6.0%*
Bongolava	52	52	3	107	*4.4%*	100	82	3	185	*7.6%*
Haute Mahatsiatra	58	57	26	141	*5.8%*	116	25	10	151	*6.2%*
Amoron'i Mania	78	71	0	149	*6.1%*	51	41	0	92	*3.8%*
Vatovavy Fitovinany	113	3	50	166	*6.8%*	47	0	1	48	*2.0%*
Ihorombe	53	3	0	56	*2.3%*	104	22	54	180	*7.4%*
Atsinanana	64	2	51	117	*4.8%*	52	1	2	55	*2.3%*
Analanjirofo	62	0	52	114	*4.7%*	2	0	0	2	*0.1%*
Alaotra Mangoro	53	0	16	69	*2.8%*	61	0	0	61	*2.5%*
Boeny	44	0	52	96	*4.0%*	116	3	289	408	*16.8%*
Sofia	1	68	0	69	*2.8%*	15	100	0	115	*4.9%*
Betsiboka	57	8	0	65	*2.7%*	104	99	2	205	*8.4%*
Melaky	60	84	0	144	*5.9%*	46	21	0	67	*2.8%*
Atsimo Andrefana	51	0	0	51	*2.1%*	53	0	0	53	*2.2%*
Androy	63	60	22	145	*6.0%*	54	52	16	122	*5.0%*
Anosy	79	0	0	79	*3.3%*	2	0	0	2	*0.1%*
Menabe	52	52	0	104	*4.3%*	94	68	0	162	*6.7%*
Diana	54	39	0	93	*3.8%*	106	49	1	156	*6.4%*
Sava	84	0	2	86	*3.5%*	52	0	0	52	*2.1%*
Total	1 398	649	381	2 428	*100.0%*	1 398	649	381	2 428	*100.0%*
	57.6%	*26.7%*	*15.7%*	*100.0%*		*57.6%*	*26.7%*	*15.7%*	*100.0%*	

Source: Authors
Note: The unit of observation is market–origin–week–category (N = 22 x 22 x 52 x 3 = 75 504). Intra-regional flows are included.

3.2 Annual regional flows

The regional flows of *vary gasy*, *tsipala* and *makalioka* are presented in a matrix[11] in Table 3. By glancing at Table 3 it is clear that the dominant form of rice flow for *vary gasy* and *tsipala* is intra-regional. For these two categories of rice, inter-regional flows are not observed consistently throughout the year, and neither are they observed between distant regions. For *makalioka* it is the opposite: intra-regional transactions are rare because the producing regions in this category of rice are limited and concentrated in Alaotra Mangoro.

[11] The rows indicate the "origins" – the producing regions where the rice comes from. The columns indicate the "destinations" – the consuming markets into which the rice flows. The intra-regional flow is on the diagonal line, while the inter-regional flow is off the diagonal line. The number in each cell indicates the frequency of the flow across the observations over 52 weeks. To show the degree of link strength, a flow that occurs for more than 26 weeks during the 52 weeks is shaded in grey.

Table 3: Rice flow by category

a) Vary gasy

Origin \ Destination	Analamanga	Vakinankaratra	Itasy	Bongolava	Haute Matsiatra	Amoron'I Mania	Vatovavy Fitovinany	Ihorombe	Atsimo Atsinanana	Atsinanana	Analanjirofo	Alaotra Mangoro	Boeny	Sofia	Betsiboka	Melaky	Atsimo Andrefana	Androy	Anosy	Menabe	Diana	Sava
Analamanga	3														3							
Vakinankaratra	1	52			2																	
Itasy	52		52											5								
Bongolava	38		1	52		9																
Haute Matsiatra		3			52		50		8									3				
Amoron'I Mania						51																
Vatovavy Fitovinany							47															
Ihorombe							13	52	4								4	31				
Atsimo Atsinanana									52													
Atsinanana										2												
Analanjirofo										9	52											
Alaotra Mangoro	14	2				1	3			51	1	44										
Boeny	2				2	8							4		3							
Sofia	1				2	9							1	52	8						31	
Betsiboka															46							
Melaky																51				2		
Atsimo Andrefana																	52	2				
Androy																		2				
Anosy								1										41	52			
Menabe		47															7			52		
Diana																					52	
Sava																					1	52

b) Tsipala

Origin \ Destination	Analamanga	Vakinankaratra	Itasy	Bongolava	Haute Matsiatra	Amoron'I Mania	Vatovavy Fitovinany	Ihorombe	Atsimo Atsinanana	Atsinanana	Analanjirofo	Alaotra Mangoro	Boeny	Sofia	Betsiboka	Melaky	Atsimo Andrefana	Androy	Anosy	Menabe	Diana	Sava
Analamanga							1															
Vakinankaratra		50																				
Itasy	9		26																			
Bongolava	29		1	52																		
Haute Matsiatra					25																	
Amoron'I Mania						41																
Vatovavy Fitovinany																						
Ihorombe					16		2	3	1													
Atsimo Atsinanana									1													
Atsinanana																						
Analanjirofo																						
Alaotra Mangoro	2	1																				
Boeny	6					9							52		33							
Sofia	23		1			21							16	8	30							
Betsiboka															21							
Melaky																						
Atsimo Andrefana																	52					
Androy																						
Anosy					16														52			
Menabe		2															8			39		
Diana																						
Sava																						

c) Makalioka

Origin \ Destination	Analamanga	Vakinankaratra	Itasy	Bongolava	Haute Matsiatra	Amoron'I Mania	Vatovavy Fitovinany	Ihorombe	Atsimo Atsinanana	Atsinanana	Analanjirofo	Alaotra Mangoro	Boeny	Sofia	Betsiboka	Melaky	Atsimo Andrefana	Androy	Anosy	Menabe	Diana	Sava
Analamanga																						
Vakinankaratra		1																				
Itasy	2																					
Bongolava				3																		
Haute Matsiatra							9		1													
Amoron'I Mania																						
Vatovavy Fitovinany							1															
Ihorombe							7		47													
Atsimo Atsinanana									2													
Atsinanana																						
Analanjirofo																						
Alaotra Mangoro	52	52			26		33		1	52	16	52					5					
Boeny																						
Sofia																					2	
Betsiboka																						
Melaky																						
Atsimo Andrefana																	16					
Androy																						
Anosy																						
Menabe																	1					
Diana																						
Sava																						

Source: Authors. Unit of observation: market–origin–week (max: 22 x 22 x 52). The unit per market pair is week (max = 52), i.e. the numbers indicate the frequency of the flow within the 52-week observations.

Figure A1 in the Appendix depicts the rice flow[12] map of each category based on Table 3. The black dots indicate the rice-surplus markets and the grey dots indicate the rice-deficit markets. For *vary gasy*, most of the markets are connected to each other and are not spatially segregated; however, the connections are mostly limited to nearby regions. Only a few regions are engaged in long-distance trade, which also tends to be seasonal (shorter than 26 weeks). Rice generally flows from surplus to deficit markets; however, some rice-surplus markets (e.g. Amoron'i Mania and Betsiboka) import rice without exporting it, while Ihorombe, a rice-deficit market, exports rice without importing.[13] For *tsipala* and *makalioka*, the network is much sparser and less connected.

3.3 Seasonality of the flows

Figure 3 indicates the number of destination regions experiencing inflows by type of flow (i.e. inter- and intra-regional) for each of the rice categories during the 52-week period. The unit of observation is the market ($N = 22$) for each category–week. Figure 3 indicates that most of the regions self-support *vary gasy*, meaning that intra-regional flows are dominant. For *tsipala*, approximately half (10 regions) are self-supporting. For *makalioka*, very few regions can self-support and inter-regional flows are clearly dominant.

Figure 3 also shows that inter-regional flow increases during the off-harvest season. The number of regions with inflows from other regions increases between October and January and between September and January for *vary gasy* and *tsipala* respectively. This suggests that, as *vary gasy* and *tsipala* are traded primarily within their regions of production, inter-regional trade increases when locally produced rice is less available in the market during the off-harvest season. The inter-regional flow of *makalioka*, although stable throughout the year, also increases slightly during the off-harvest season.

[12] We omit rice flows with only one week's observation in Figure A1, as they may not constitute a trend.
[13] For clarity's sake, it might be worth mentioning that the network is not of the hub–spoke type. This might be because we observed only the origin of the rice, not of the transportation.

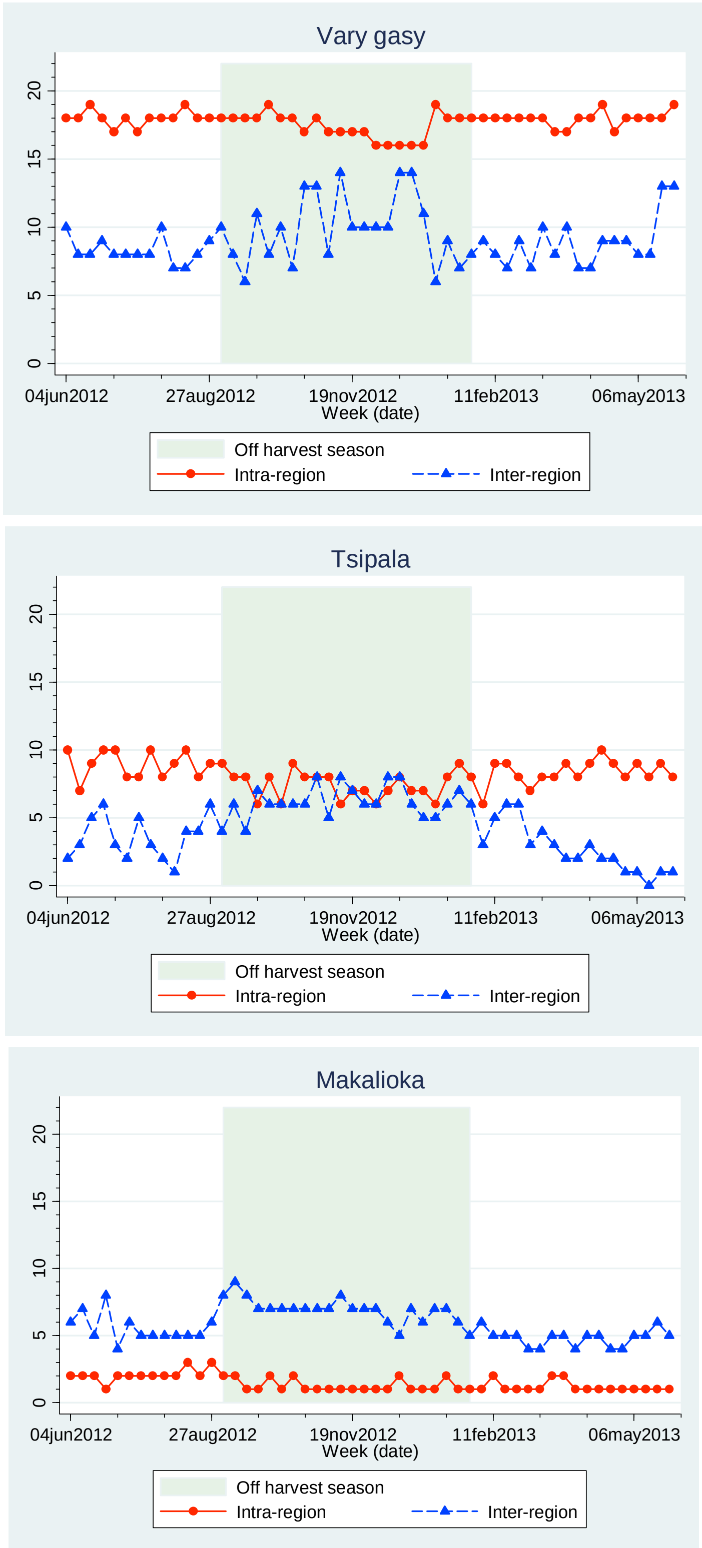


Figure 3: Number of regions with inflows by type of flow

Source: Authors (Data for inflows by type of flow from Madagascar Retailer Survey 2012-2013, data showing off-harvest months from FEWS NET (2013a) and the Ministry of Agriculture, Livestock and Fishery (2007))

To summarise, for *vary gasy* and *tsipala*, intra-regional flows tend to be dominant and inter-regional flows are primarily seasonal, whereas *makalioka* has more inter-regional flows because the producing regions are limited. Transportation costs might matter for inter-regional flows, as inter-regional trade appears to occur when the market and origin are adjacent. Regarding seasonality, inter-regional flows increase slightly during the off-harvest season. The next section provides a more detailed analysis of the relevance of these findings.

4. Accounting for the pattern of inter-regional rice flow

This section focuses on the inter-regional rice flow patterns. We predict that rice flow is affected by each region's rice sufficiency and by proximity between regions. We first examine the binary relation between rice flow and these factors and then proceed to a multivariate regression analysis based on Equation (1).

4.1 Bivariate analysis

4.1.1 Rice sufficiency, proximity, and seasonality

Table 4 shows the bivariate relation between rice flow and each factor. We report the percentage of inflow observations using (1) the market's rice sufficiency status (deficit vs. surplus); (2) market–origin proximity (adjacent vs. non-adjacent); and (3) the market's seasonality (rainy vs. dry season, and harvest vs. off-harvest season). The p-values of a test of proportions, or Welch's t-test for the equality of proportions or means, are also reported.

Table 4: Bivariate relations of inflows and potential factors

Markets' rice sufficiency (unit of obs. = market; *N* = 22)					**Origin is adjacent (unit of obs. = market origin, *N* = 462)**				
	Deficit	Surplus	Difference	*p*-value		Not adjacent	Adjacent	Difference	*p*-value
	(*n* = 10)	(*n* = 12)				(*n* = 362)	(*n* = 100)		
Percentage of observations with inflow (max = 1)					Percentage of observations with inflow (max = 1)				
Any variety	0.800	0.750	0.050	0.781	Any variety	0.058	0.260	-0.202	**0.000**
Vary gasy	0.800	0.750	0.050	0.781	Vary gasy	0.041	0.250	-0.209	**0.000**
Tsipala	0.300	0.583	-0.283	0.184	Tsipala	0.022	0.120	-0.098	**0.000**
Makalioka	0.600	0.250	0.350	0.096	Makalioka	0.014	0.100	-0.086	**0.000**
Number of weeks with inflow (max = 52)					Number of weeks with inflow (max = 52)				
Any variety	30.6	15.9	14.7	0.125	Any variety	0.6	6.3	-5.7	**0.000**
Vary gasy	25.0	8.2	16.8	0.072	Vary gasy	0.3	3.8	-3.6	**0.003**
Tsipala	5.0	9.4	-4.4	0.456	Tsipala	0.2	1.5	-1.3	**0.033**
Makalioka	20.9	7.0	13.9	0.135	Makalioka	0.2	2.3	-2.1	**0.038**

Market is rainy season (unit of obs. = market-week; *N* = 1.144)					**Market is harvest season (unit of obs. = market-week; *N* = 1.144)**				
	Dry	Rainy	Difference	*p*-value		Off-harvest	Harvest	Difference	*p*-value
	(*n* = 650)	(*n* = 494)				(*n* = 849)	(*n* = 295)		
Percentage of observations with inflow (max = 1)					Percentage of observations with inflow (max = 1)				
Any variety	0.431	0.439	-0.009	0.774	Any variety	0.463	0.353	0.110	**0.001**
Vary gasy	0.308	0.300	0.008	0.768	Vary gasy	0.314	0.275	0.040	0.199
Tsipala	0.142	0.144	-0.002	0.917	Tsipala	0.163	0.085	0.078	**0.001**
Makalioka	0.265	0.245	0.020	0.450	Makalioka	0.249	0.278	-0.029	0.318

Source: Authors (Data for inflows by rice category from Madagascar Retailer Survey 2012-2013; data for market surplus and deficit from Ministry of Agriculture and Rural Development (2014), FEWS NET (2013b) and INSTAT (1005; 2010); data for market proximity from National Hydrographic and Geographic Institute in Madagascar; data for rainy season and harvest season from FEWS NET (2013a) and the Ministry of Agriculture, Livestock and Fishery (2007)).
Note: p-values of test of proportions on equality of proportions reported for percentages of observations, and p-values of Welch's two-sample t-test reported on the equality of means reported for number of weeks. Those lower than 5% are emphasised in bold.

Several notable observations emerge. First, rice-deficit regions tend to experience inflows more frequently than surplus regions do. The unit of observation is the market (N = 22). The percentage of regions experiencing inflows during the observation period does not differ substantially between surplus and deficit regions, given that most markets import rice from other regions regardless of their rice-sufficiency status. However, the mean number of weeks with inflows for any rice category (maximum = 52 weeks) is almost twice as high for deficit markets than for surplus markets (30.6 weeks vs. 15.9 weeks, p = 0.125).

Second, inflows are more common between adjacent market–origin pairs than between non-adjacent pairs. The unit of observation is directed market–origin pairs, excluding intra-regional trade (N = 22 x 21 = 462). The percentage experiencing inflows is 4.5 times higher for adjacent pairs than for non-adjacent pairs (26.0% vs. 5.8%, p < 0.000; any category), and the mean number of weeks with inflows is greater for adjacent pairs (6.3 weeks vs. 0.6 weeks, p < 0.000; any category). The mean-adjusted Lowess smoother of inflows on road distance (km) depicted in Figure 4 supports this observation. Figure 4 indicates that the probability of inflow diminishes with road distance between market and origin, and converges to almost zero when the regions are more than 1 500 km apart.

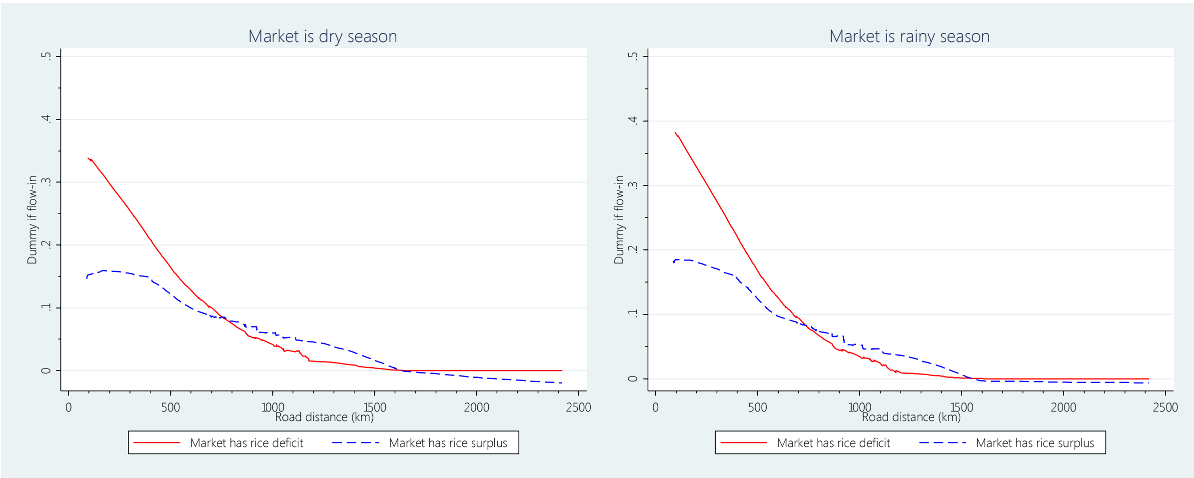


Figure 4: Mean adjusted Lowess smoother of inflows on road distance

Source: Authors (Data for inflows from Madagascar Retailer Survey 2012-2013, data for road distance from National Hydrographic and Geographic Institute in Madagascar)

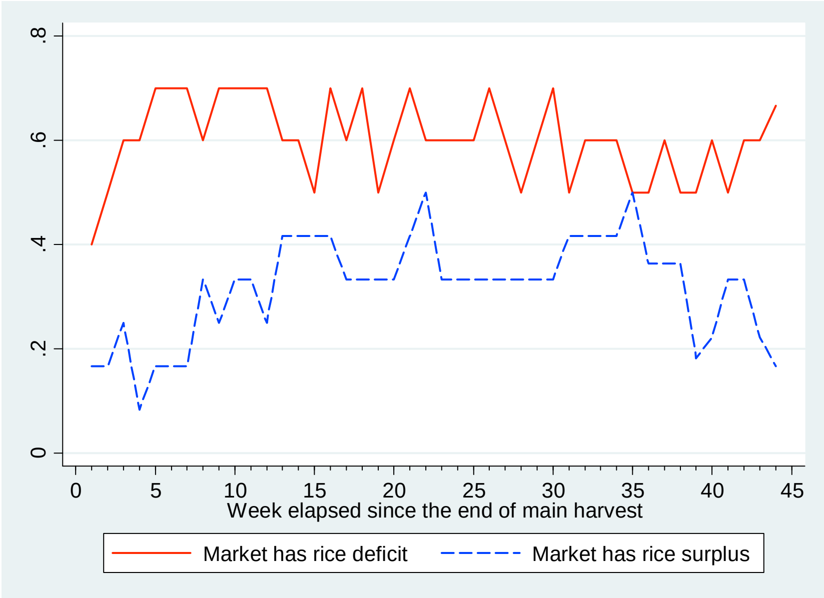
Note: The unit of observation is directed market–origin pairs (excluding intra-regional flow) (N = 22 × 21 = 462).

Third, we find no evidence indicating that the rainy season reduces inflows. The percentages of market–week observations (N = 22 x 52 = 1 144) are almost equivalent for the dry and rainy seasons (43.1% vs. 43.9%, p = 0.774; any rice category).

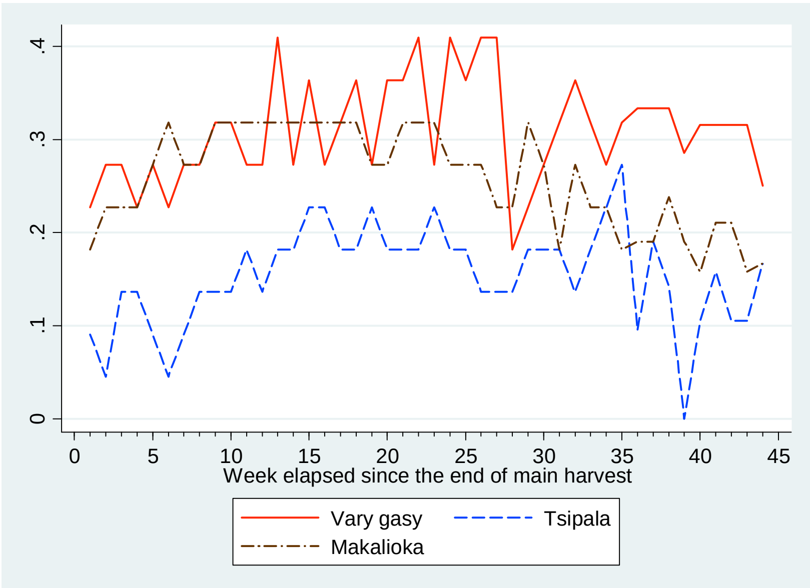
Fourth, we find indicative signs that the occurrence of inflows is higher for the off-harvest season than for the harvest season (46.3% vs. 35.3%, p = 0.001; N = 1 144; any rice category). However, this tendency is not as apparent in a breakdown based on rice category.

4.1.2 Weeks elapsed since the last main harvest

Because the extent of regions' rice self-sufficiency changes over time, we also predict that the prevalence of rice inflows increases as time passes after the main harvest season. Figure 5a depicts the percentage of markets experiencing inflows for any rice category based on weeks elapsed since the end of the main harvest (defined for each market). The unit of observation is market–week (elapsed).[14] Figure 5a indicates that rice-deficit regions have higher inflow percentages than surplus regions throughout the year. For rice-deficit regions, the percentages increase from 40% to 60% by the third week, although the overall trend is stable. For rice-surplus regions, the percentage climbs steadily from 17% in the first week to 42% in the thirteenth week. However, the increasing pattern is not clear. Figure 5b depicts the inflow percentage based on rice category, which increases over the weeks that elapse for *tsipala*. However, Figure 5b does not offer a clear, definitive trend.



(a) By market's rice sufficiency (any category)



(b) By rice category

Figure 5: Frequency of inflows by week elapsed since the last main harvest

Source: Authors (Data for inflows by rice category from Madagascar Retailer Survey 2012-2013; data for market surplus and deficit from Ministry of Agriculture and Rural Development (2014), FEWS NET (2013b) and INSTAT (2005; 2010); data for harvest season from FEWS NET (2013a) and the Ministry of Agriculture, Livestock and Fishery (2007))

Note: The unit of observation is market–week (elapsed). Eight observations with elapsed weeks higher than 45 are truncated and presented as single observations. The remaining total number of observations is 942.

[14] We truncated the period to 45 weeks because only one market, Androy, has a longer elapsed week, given that this region does not have a main harvest season. Thus, the final number of observations is 942.

4.2 Regression analysis

We conducted multivariate regression analyses to better understand the factors associated with inter-regional flows, *ceteris paribus*.

Table 5 reports the estimation results from the logistic regression model based on Equation (1). The unit of observation is (directed) market–origin–week–category (N = 72 072), and the effect size is reported as an odds ratio. The 95% confidence interval (CI) is calculated using robust standard errors clustered by (non-directed) market–origin pairs. Columns (1) to (4) use the road distance (km) between origin j and market i as a measure of the proximity between regions, whereas columns (5) to (8) use a dummy indicating that two regions are adjacent. For each specification, we first run a regression that pools all rice categories (columns [1] and [5]), and then a separate regression for each category.

Table 5: Estimates of logistic regression of inflows from origin *j* to market *i*

Dep. var. = dummy if inflow	**All varieties**	**Vary gasy**	**Tsipala**	**Makalioka**	**All varieties**	**Vary gasy**	**Tsipala**	**Makalioka**
(Odds ratio)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Market *i* has deficit (dummy)	7.918**	11.11**	0.425	2.894	8.528**	12.90**	0.423	2.921
	[1.821, 34.42]	[2.032, 60.71]	[0.0414, 4.366]	[0.698, 12.01]	[1.795, 40.52]	[2.656, 62.64]	[0.0398, 4.495]	[0.651, 13.11]
Origin *j* has surplus (dummy)	9.810***	8.631**	7.655	1.993	10.16***	9.143**	7.823*	1.92
	[2.901, 33.17]	[2.037, 36.58]	[0.957, 61.21]	[0.260, 15.25]	[3.124, 33.05]	[1.966, 42.52]	[1.053, 58.09]	[0.224, 16.42]
Origin *j* has surplus (dummy) *	0.314	0.46	1.577		0.278	0.349	1.498	
Market *i* has deficit (dummy)	[0.0557, 1.772]	[0.0670, 3.153]	[0.0627, 39.69]		[0.0499, 1.544]	[0.0522, 2.331]	[0.0630, 35.60]	
Distance between *i*-*j* (100 km)	0.704***	0.617***	0.765*	0.758***				
	[0.609, 0.812]	[0.493, 0.773]	[0.614, 0.954]	[0.665, 0.865]				
Regions *i*-*j* is adjacent (dummy)					12.17***	18.01***	5.861**	13.09**
					[4.950, 29.93]	[6.472, 50.13]	[1.759, 19.53]	[2.621, 65.40]
Market *i* is rainy season (dummy)	1.17	1.677*	0.498	1.165	0.941	1.239	0.483	0.888
	[0.767, 1.784]	[1.078, 2.609]	[0.200, 1.235]	[0.656, 2.071]	[0.563, 1.571]	[0.747, 2.056]	[0.197, 1.187]	[0.436, 1.809]
Origin *j* is rainy season (dummy)	1.048	0.716	0.460***	3.152*	0.915	0.693	0.439***	2.088
	[0.576, 1.904]	[0.277, 1.851]	[0.292, 0.725]	[1.227, 8.096]	[0.571, 1.465]	[0.302, 1.590]	[0.273, 0.706]	[0.821, 5.309]
Market *i* is harvest season (dummy)	0.858	0.736	0.74	1.289	0.887	0.799	0.73	1.306
	[0.612, 1.203]	[0.416, 1.302]	[0.426, 1.285]	[0.807, 2.058]	[0.623, 1.263]	[0.458, 1.393]	[0.409, 1.305]	[0.827, 2.065]
Origin *j* is harvest season (dummy)	1.603***	1.244	2.753**	1.620**	1.464**	1.17	2.454**	1.415*
	[1.219, 2.109]	[0.822, 1.882]	[1.404, 5.400]	[1.205, 2.179]	[1.146, 1.870]	[0.845, 1.621]	[1.361, 4.424]	[1.038, 1.931]
Variety (Reference: Vary gasy)								
Tsipala	0.456				0.455			
	[0.192, 1.082]				[0.191, 1.082]			
Makalioka	0.623				0.622			
	[0.353, 1.102]				[0.353, 1.096]			
N	72 072	24 024	23 562	17 784	72 072	24 024	23 562	17 784
pseudo R-sq	0.200	0.286	0.173	0.128	0.201	0.258	0.165	0.168
Log likelihood	-4 249.3	-1 668.4	-1 058.7	-1 348.3	-4 241.4	-1 733.8	-1 068.3	-1 286.9

Source: Authors (Data for inflows by rice category from Madagascar Retailer Survey 2012-2013; data for market surplus and deficit from Ministry of Agriculture and Rural Development (2014), FEWS NET (2013b) and INSTAT (2005; 2010); data for market proximity from National Hydrographic and Geographic Institute in Madagascar; data for rainy season and harvest season from FEWS NET (2013a) and the Ministry of Agriculture, Livestock and Fishery (2007))

Note: The unit of observation is (directed) market–origin–week–category (N = 72,072). Intra-regional flows are excluded. Effect sizes are reported in the odds ratio. The 95% confidence interval is reported in brackets using robust standard errors clustered by market. Week fixed-effects are included but are not reported. Samples are omitted in some specifications given perfect predictions. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5 indicates several statistical patterns. First, regarding rice sufficiency, deficit regions tend to import rice, a result consistent with our expectation. The odds ratio of the deficit market dummy is 7.918 (95% CI: 1.821 to 34.42) when all rice categories are pooled (column [1]). Thus, deficit regions are 7.9 times more likely to import rice than surplus regions are. This observation is reversed, however, for *tsipala* (columns [3] and [7]), indicating that surplus regions are more likely to import *tsipala* than are deficit regions (although the 95% CI is rather wide and crosses unity). The probability of inflows is also high when the origin is a surplus region. The odds ratio of the surplus origin dummy is 9.810 (95% CI: 2.901 to 33.17) in column (1): the probability of importing from a surplus origin is 9.8 times higher than that of importing from a deficit origin. The interaction term of those variables is not statistically significant; however, it does indicate that no complementary effect occurs between market–deficit and origin–surplus matches.[15]

Second, regarding the proximity between origin and destination, we find that trade does occur between proximate regions: column (1) indicates that the odds ratio of road distance (100 km) is 0.704 (95% CI: 0.609 to 0.812), implying that an additional 100 km of road distance between two regions reduces the probability of inflows by 30%. Column (5) indicates that the odds ratio of adjacent regions is 12.12 (95% CI: 5.382 to 27.29), implying that the probability of importing rice from adjacent regions is 12.1 times higher than that of importing from non-adjacent regions. These results hold true for the separate regression of each rice category, although the magnitude differs.

Third, in terms of seasonality, the results of the rainy season dummies are mixed and unstable. Although we expect that the rainy season hampers the efficient physical spatial distribution of rice, the odds ratios are not consistently lower than one.[16] However, the effects of the harvest season generally follow a logical pattern: the probability of inflows is higher when the origins are in harvest season.[17]

Finally, flows of *tsipala* and *makalioka* are less frequent than are those of *vary gasy*. The odds ratio of the *tsipala* dummy in column (1) is 0.456 (95% CI: 0.192 to 1.082) and that of *makalioka* is 0.623 (95% CI: 0.353 to 1.102). Thus, the probability of inflows for *tsipala* and *makalioka* is 54% and 38% lower respectively than it is for *vary gasy*, even though the coefficients are not statistically significant.

To examine whether rice inflows increase over time after the main harvest, we estimated the regression shown in Table 5 with an additional variable for weeks elapsed since the last main harvest. We limited our observation to weeks in the off-main harvest season, because this variable is defined only for this specific season. The results are reported in Table 6. Although we expected that the inflow probability would increase as weeks elapse after the main harvest, the results indicate no clear support for such a prediction. We also expected that such an effect would be stronger for rice-deficit regions, and thus that the interaction term of the weeks elapsed and the deficit market dummy would be smaller than unity. Again, no obvious pattern appears, except for *tsipala*, which indicates that the effect is magnified by rice deficiency.

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[15] The coefficients for *makalioka* are dropped (columns 4 and 8) because the interaction term perfectly predicts the inflow.

[16] We also run regressions with interaction terms between the rainy season dummy and distance, expecting that the negative impacts of physical distance are augmented in the rainy season, when road conditions become unfavourable, especially on unpaved roads. The coefficients of the interaction terms, however, are statistically insignificant. For the sake of brevity, we show the estimation results without those interaction terms.

[17] To display the detailed seasonal pattern, Figure A2 in the Appendix indicates the average predicted probability of inflows for each week by market rice-sufficiency status based on the estimates in Table 4, columns (6) to (8). The most active season differs among rice categories. While the probability of inflows is constant for *vary gasy*, an increase is observed between the periods of November to March and September to October for *tsipala* and *makalioka* respectively.

Table 6: Estimates of logistic regression of inflows from origin *j* to market *i* with weeks elapsed since the main harvest

Dep. var.= dummy if inflow	**All varieties**	**Vary gasy**	**Tsipala**	**Makalioka**	**All varieties**	**Vary gasy**	**Tsipala**	**Makalioka**
(Odds ratio)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Market *i* has deficit (dummy)	8.312**	11.28**	1.111	2.431	9.358**	13.43**	1.212	2.554
	[1.927, 35.85]	[2.187, 58.22]	[0.101, 12.21]	[0.621, 9.524]	[1.969, 44.47]	[2.711, 66.50]	[0.108, 13.63]	[0.584, 11.18]
Origin *j* has surplus (dummy)	8.295***	6.738**	7.502	1.842	8.552***	7.174*	7.605*	1.766
	[2.506, 27.46]	[1.658, 27.37]	[0.912, 61.73]	[0.228, 14.87]	[2.674, 27.35]	[1.580, 32.58]	[1.013, 57.09]	[0.195, 15.98]
Origin *j* has surplus (dummy)*	0.358	0.593	1.217		0.318	0.441	1.172	
Market *i* has deficit (dummy)	[0.0614, 2.089]	[0.0798, 4.411]	[0.0456, 32.46]		[0.0551, 1.839]	[0.0607, 3.202]	[0.0466, 29.51]	
Weeks elapsed since main harvest	1.006	1.013	1.029	0.977	1.012	1.018	1.034*	0.985
	[0.985, 1.027]	[0.981, 1.046]	[0.987, 1.073]	[0.944, 1.011]	[0.994, 1.031]	[0.993, 1.043]	[1.001, 1.068]	[0.954, 1.017]
Weeks elapsed since main harvest*	0.990	0.990	0.962**	1.008	0.988	0.990	0.956**	1.006
Market *i* has deficit (dummy)	[0.977, 1.004]	[0.962, 1.019]	[0.937, 0.988]	[0.982, 1.033]	[0.973, 1.003]	[0.963, 1.017]	[0.930, 0.983]	[0.982, 1.030]
Distance between *i-j* (100 km)	0.705***	0.612***	0.780*	0.757***				
	[0.606, 0.819]	[0.487, 0.769]	[0.618, 0.985]	[0.656, 0.874]				
Regions *i-j* is adjacent (dummy)					11.55***	17.01***	5.275*	13.55**
					[4.560, 29.23]	[5.857, 49.40]	[1.482, 18.77]	[2.546, 72.06]
Market *i* is rainy season (dummy)	0.925	1.199	0.366*	1.102	0.823	1.053	0.350*	0.87
	[0.599, 1.427]	[0.663, 2.167]	[0.148, 0.908]	[0.628, 1.936]	[0.525, 1.292]	[0.667, 1.660]	[0.146, 0.837]	[0.438, 1.727]
Origin *j* is rainy season (dummy)	1.105	0.875	0.447***	3.586*	0.987	0.849	0.418***	2.584*
	[0.559, 2.185]	[0.300, 2.553]	[0.283, 0.706]	[1.304, 9.865]	[0.554, 1.759]	[0.318, 2.264]	[0.250, 0.701]	[1.028, 6.498]
Market *i* is harvest season (dummy)	0.737	0.713	0.297	1.265	0.773	0.784	0.302	1.348
	[0.434, 1.254]	[0.375, 1.355]	[0.0689, 1.281]	[0.679, 2.359]	[0.437, 1.368]	[0.387, 1.589]	[0.0694, 1.318]	[0.713, 2.549]
Origin *j* is harvest season (dummy)	1.587*	1.381	3.122**	1.22	1.39	1.179	2.726***	1.034
	[1.036, 2.433]	[0.811, 2.351]	[1.544, 6.312]	[0.836, 1.781]	[0.967, 1.996]	[0.777, 1.790]	[1.616, 4.599]	[0.682, 1.569]
Variety (Reference: Vary gasy)								
Tsipala	0.471				0.47			
	[0.195, 1.140]				[0.194, 1.138]			
Makalioka	0.603				0.602			
					[0.322, 1.127]			
N	59 850	19 950	18 795	14 890	59 850	19 950	18 795	14 890
pseudo R-sq	0.196	0.291	0.171	0.13	0.194	0.254	0.164	0.172
Log likelihood	-3 616.8	-1 406	-918.7	-1 115.2	-3 626	-1 478.4	-925.9	-1 061.9

Source: Authors (Data for inflows by rice category from Madagascar Retailer Survey 2012-2013; data for market surplus and deficit from Ministry of Agriculture and Rural Development (2014), FEWS NET (2013b) and INSTAT (2005; 20100; data for market proximity from National Hydrographic and Geographic Institute in Madagascar; data for rainy season and harvest season from FEWS NET (2013a) and the Ministry of Agriculture, Livestock and Fishery (2007))

Note: The unit of observation is (directed) market–origin–week–category ($N = 72,072$). Intra-regional flows are excluded. Samples are limited to off-main harvest weeks. Effect sizes are reported in the odds ratio. The 95% confidence interval is reported in brackets using robust standard errors clustered by market. Week fixed-effects are included but are not reported but are not reported. Samples are omitted in some specifications given perfect predictions. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

5. Discussion

The inter-regional rice flow patterns in Madagascar indicate that rice tends to flow from surplus regions to deficit ones and that inter-regional rice trade is more frequent between proximate areas. This finding is consistent with the common assumption that flows are directed toward deficit regions and that physical trade is easier and cheaper between proximate regions.

Other findings appear counterintuitive, however. First, in terms of seasonality, we found no evidence to indicate that the rainy season reduces flows, which was almost equivalent across all rice categories during the dry season and the rainy season. The general belief is that the rainy season hampers physical distribution because of its detrimental effect on road infrastructure. However, most inter-regional flows we observed occur on paved roads, which are more weather resistant. If this study included data at the district level, the results would likely show that weather has a significantly negative effect on trade.

Second, we found no evidence that inflows become more active as time elapses after the main harvest, although the destination region is supposed to run out of stock. Although we found that the probability of inflows into destinations declines during the harvest season (as captured by the harvest season dummy), no consistent evidence suggests that the probability of inflows declines during the weeks following the main harvest (see Table 5). This may indicate that markets import rice relatively consistently throughout the year. One possible explanation for this result is that deficit markets engage in imports during the harvest season because rice is cheaper in surplus regions during that period. Another possibility is that deficit markets set aside their own production as a buffer for use during the pre-harvest season.

Some limitations in our data include the following. The first is with regard to the regional representativeness of the survey site. Some inter-regional links could have been overlooked because the region is represented only by the regional capital. We might have observed more inter-regional links if we had conducted the survey in urban centres close to other districts.

The second limitation is related to the number of sampled traders per market. Although we randomly selected five retailers per market every week, this sample might not capture all trade flows, particularly in large markets, thereby resulting in underestimation. Our number of sample retailers also prevented us from obtaining credible estimates of total sales volumes. Employing a sampling technique that better reflects the differences in the size of each market would have been preferable, although costly, as a way to increase the accuracy of the estimates.

The third limitation is related to the occurrence of inter-regional trade. Our data capture the origins of the rice sold in each market every week, but do not necessarily match the actual shipments from one region to another during that period, especially if there are enough stocks in the destination markets. Therefore, even if a product from one region is sold in another region every week all year round, this does not mean that trade in fact occurs between the two regions every week. Obtaining more precise information on actual physical flows would require including truckers, millers and wholesalers in the survey.

6. Conclusion

This study explores how markets are spatially distributed and linked, and how and when rice is traded in Madagascar. The analysis of the flows of the three main categories of local rice shows that, for the two categories that represent 84% of the observations (*vary gasy* and *tsipala*), rice is traded primarily within the region of production and inter-regional flow is only seasonal, even though *makalioka*, which represents only 16% of the observations, has more inter-regional flows than intra-regional flows. These strong overall intra-regional rice trade patterns might be caused by the differences in consumer tastes across regions (Sakurai *et al*. 2015), as well as high transaction and transportation costs (Fafchamps *et al*. 2005). This relative regional self-sufficiency might also explain the weak integration of rice markets in Madagascar found by Moser *et al*. (2009).

In terms of the direction of inter-regional rice flows, it is not a one-way trajectory from surplus to deficit regions, as we found movements in both directions. At the same time, rice-deficit regions tend to import rice from rice-surplus regions, particularly from adjacent surplus regions. This finding supports prior research on trade flows in Sub-Saharan Africa and their impact on food availability, namely those claiming that commodities flowing from surplus to deficit regions contributes positively to food availability. Therefore, trade flows of rice appear to be contributing to food availability in the regional capital markets.

What we did not expect to find was that the probability of inflows did not increase over time after the main harvest season, and that the rainy season had a negligible impact on inter-regional trade. For the first finding, this might be explained by the possibility that deficit regions import consistently throughout the year. For the second, the fact that the rainy season did not appear to hamper the inter-regional trade of rice contests other findings that have revealed the opposite. This could be due to recent improvements to the roads connecting regions. From these two findings, it appears that there is consistent connectivity among regional capital markets throughout the year. Further studies on market integration in Madagascar can build upon this information to examine if these inter-regional flows are optimal.

In terms of policy implications, our findings shed light on the importance of investing in road infrastructure to foster trade. Given that the rice trade is highly intra-regional, which suggests some degree of regional self-reliance, but also that inter-regional transportation costs are still high, it seems necessary to further improve road networks, both intra- and inter-regional. Improving road infrastructure would not only increase connectivity across regions, but would also enhance agricultural productivity and supply responses (World Bank 2009). As roads connecting regions already appear to be in a relatively good condition, further research is needed to identify why inter-regional transportation costs remain high. Such information can be useful for identifying which policies can best link intra- and inter-regions in a way that fosters rural and urban food security.

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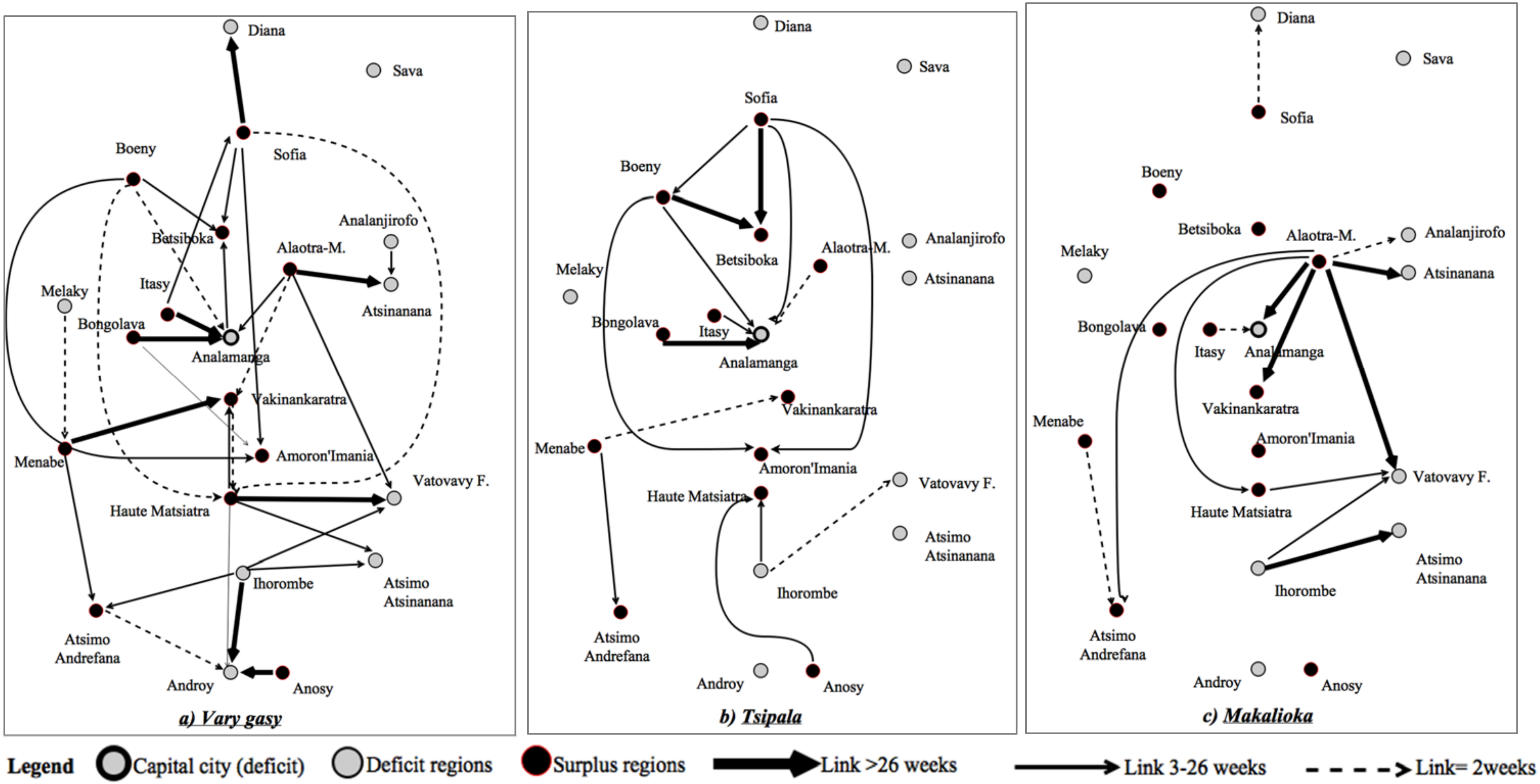
Appendix

Figure A1: Inter-regional flows by rice category



Source: Authors
Note: A link with only one week's observation is omitted

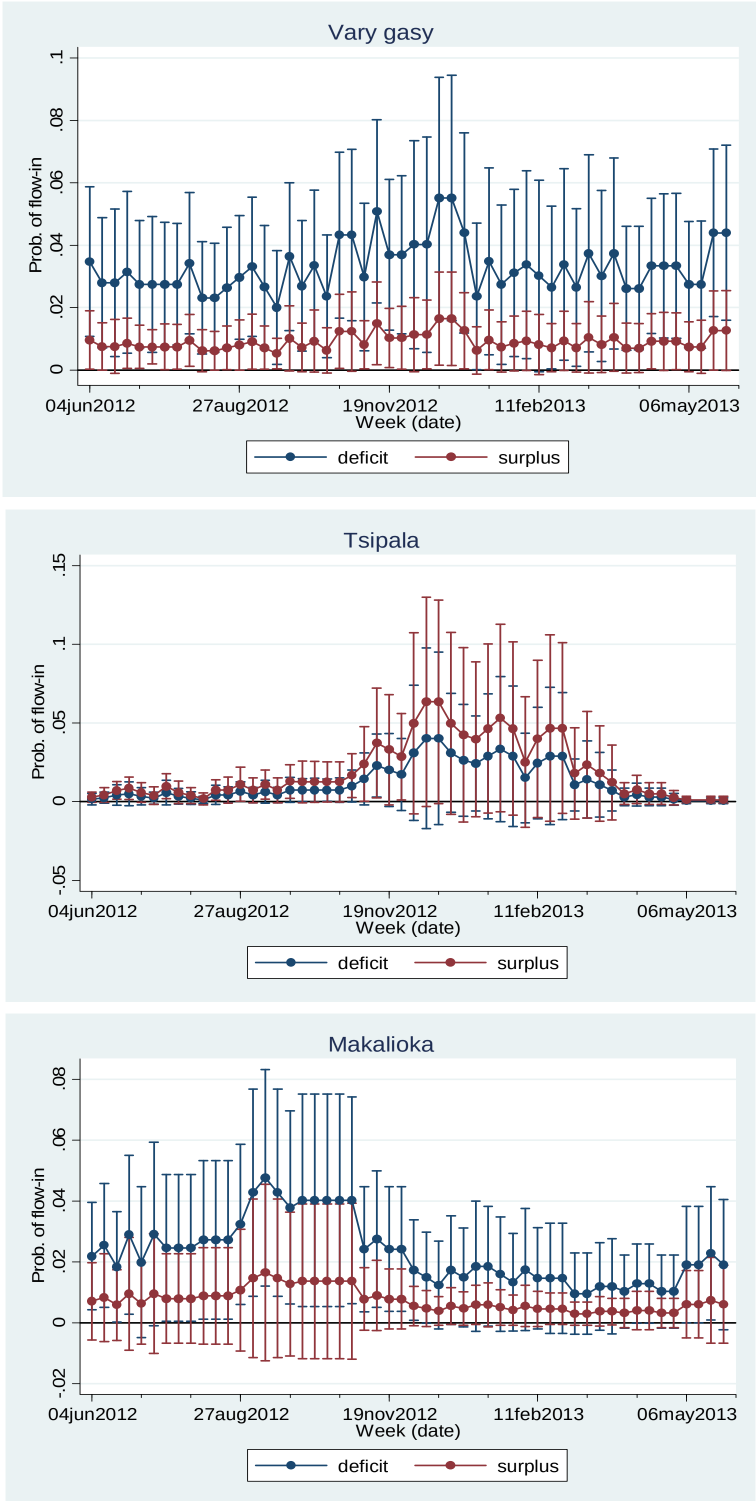


Figure A2: Average predicted probability of inflows by week
Source: Authors
Note: Prediction is based on estimates in Table 6, columns (6) to (8). Prediction is calculated over the market's rice-sufficiency status (deficit or surplus).

Table A1: Regional variables: surplus/deficit status

	Population (persons)			Per capita rice consumption (kg)		Total rice consumption (ton)			Total rice production	Difference	Rice sufficiency
Region	Total	Urban	Rural	Urban	Rural	Urban	Rural	Total	(ton)	(ton)	status
Analamanga	3 014 120	1 047 386	1 509 593	116	102	121 811	154 355	276 166	188 389	-87 777	Deficit
Analanjirofo	1 043 934	186 579	831 124	137	117	25 599	97 078	122 677	79 742	-42 935	Deficit
Atsimo Atsinanana	763 381	76 328	729 354	114	121	8 709	88 406	97 115	57 797	-39 318	Deficit
Sava	939 800	106 011	1 034 665	132	132	13 951	136 162	150 113	118 849	-31 264	Deficit
Atsinanana	1 341 983	301 070	983 779	81	69	24 417	67 924	92 341	66 595	-25 745	Deficit
Diana	611 178	199 300	356 196	164	164	32 586	58 238	90 824	70 881	-19 943	Deficit
Ihorombe	244 106	50 885	220 502	162	172	8 228	37 878	46 106	27 554	-18 552	Deficit
Vatovavy Fitovinany	1 321 930	152 655	1 238 205	71	75	10 762	92 734	103 497	96 248	-7 249	Deficit
Androy	593 565	148 415	729 354	45	37	6 708	27 059	33 767	26 882	-6 885	Deficit
Melaky	214 624	63 606	220 502	168	191	10 686	42 160	52 846	50 568	-2 279	Deficit
Anosy	671 722	84 809	576 698	93	76	7 870	43 927	51 797	63 022	11 225	Surplus
Menabe	482 822	139 934	491 890	150	123	21 018	60 641	81 659	100 323	18 664	Surplus
Atsimo Andrefana	1 272 567	322 273	1 085 550	72	59	23 042	63 707	86 749	106 494	19 745	Surplus
Sofia	1 180 537	122 972	1 051 626	178	202	21 864	212 802	234 666	256 960	22 294	Surplus
Betsiboka	301 279	46 645	339 234	130	148	6 068	50 229	56 298	94 604	38 306	Surplus
Amoron’I Mania	873 194	84 809	610 622	86	92	7 310	55 916	63 227	108 850	45 623	Surplus
Boeny	675 820	207 781	508 851	100	114	20 799	57 970	78 769	165 951	87 182	Surplus
Bongolava	410 476	55 126	424 043	140	123	7 740	52 343	60 083	160 068	99 986	Surplus
Haute Matsiatra	1 371 170	224 743	1 017 703	91	96	20 384	98 059	118 443	245 566	127 123	Surplus
Itasy	785 311	76 328	746 315	112	99	8 564	73 620	82 184	231 874	149 690	Surplus
Alaotra Mangoro	1 100 271	169 617	882 009	163	139	27 597	122 170	149 766	339 563	189 796	Surplus
Vakinankaratra	1 988 354	373 158	1 373 899	88	77	32 689	105 813	138 502	392 155	253 653	Surplus

Source: Authors (Data for population from FEWS NET (2013b); data for the percentage of urban and rural populations from INSTAT (2010); data for rice consumption per capita in urban and rural areas from INSTAT (2005); and data for rice production by region from the Ministry of Agriculture and Rural Development (2014))

Table A2: Seasonal variables: rainy season and harvest season

	Rainy season												**Harvest season**											
Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Analamanga	1	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	**1**	**1**	0	0	0	0	0	0
Vakinankaratra	1	1	1	1	0	0	0	0	0	0	1	1	0	0	**1**	**1**	**1**	0	0	0	0	0	0	0
Itasy	1	1	1	0	0	0	0	0	0	0	0	1	0	0	1	1	**1**	**1**	0	0	0	0	0	0
Bongolava	1	1	1	0	0	0	0	0	0	0	1	1	1	1	0	**1**	**1**	0	0	0	0	0	0	0
Haute Matsiatra	1	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	**1**	**1**	0	0	0	0	0	0
Amoron'I Mania	1	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	**1**	**1**	0	0	0	0	0	0
Vatovavy Fitovinany	1	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	**1**	**1**	0	0	0	0	0	1
Ihorombe	1	1	1	1	0	0	0	0	0	0	0	1	1	0	0	0	**1**	**1**	0	0	0	0	0	1
Atsimo Atsinanana	1	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	**1**	**1**	0	0	0	0	0	1
Atsinanana	1	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	**1**	**1**	0	0	0	0	1
Analanjirofo	1	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	**1**	**1**	0	0	0	0	1
Alaotra Mangoro	1	1	1	1	0	0	0	0	0	0	1	1	0	0	1	1	**1**	**1**	0	0	0	0	0	0
Boeny	1	1	1	1	0	0	0	0	0	0	0	1	0	0	1	1	0	0	0	**1**	**1**	0	0	0
Sofia	1	1	1	0	0	0	0	0	0	0	1	1	0	0	1	1	0	0	0	**1**	**1**	0	0	0
Betsiboka	1	1	1	1	0	0	0	0	0	0	0	1	0	0	**1**	**1**	**1**	**1**	0	0	0	0	0	0
Melaky	1	1	1	0	0	0	0	0	0	0	0	1	0	0	0	**1**	**1**	0	0	0	0	0	0	0
Atsimo Andrefana	1	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	**1**	**1**	0	0	0	0	0
Androy	1	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Anosy	1	1	1	1	0	0	0	0	0	0	1	1	0	0	0	**1**	**1**	**1**	0	0	0	0	0	0
Menabe	1	1	1	0	0	0	0	0	0	0	1	1	0	0	0	**1**	**1**	0	0	0	0	0	0	0
Diana	1	1	0	0	0	1	1	0	0	0	1	1	0	0	0	0	0	**1**	**1**	0	0	0	0	1
Sava	1	1	0	0	0	1	1	1	0	0	1	1	0	0	0	0	0	**1**	1	0	0	0	0	1

Source: Authors (Data from FEWS NET (2013a), Ministry of Agriculture, Livestock and Fishery (2007))

Note: “1” indicates rainy season or harvest season for that month. The main harvest season is emphasised using filled squares and bold letters.

Table A3: Region–pair variables

A. Road distance (km)

	Analamanga	Vakinankaratra	Itasy	Bongolava	Haute Matsiatra	Amoron'I Mania	Vatovavy Fitovinany	Ihorombe	Atsimo Atsinanana	Atsinanana	Analanjirofo	Alaotra Mangoro	Boeny	Sofia	Betsiboka	Melaky	Atsimo Andrefana	Androy	Anosy	Menabe	Diana	Sava
Analamanga		169	95	218	395	259	579	545	688	369	474	320	570	754	329	651	865	918	1 028	730	1 204	1 390
Vakinankaratra	169		161	226	226	90	410	376	519	538	643	489	739	923	498	659	696	749	859	561	1 373	1 559
Itasy	95	161		123	387	251	571	537	680	464	569	415	665	849	424	556	857	910	1 020	722	1 299	1 485
Bongolava	218	226	123		452	316	636	702	745	587	692	538	788	972	547	433	922	975	1 085	787	1 422	1 608
Haute Matsiatra	395	226	387	452		136	296	150	405	764	869	715	965	1 149	724	885	470	523	633	596	1 599	2 003
Amoron'I Mania	259	90	251	316	136		320	286	429	628	733	579	829	1 013	588	749	606	659	769	460	1 463	1 649
Vatovavy Fitovinany	579	410	571	636	296	320		446	109	948	1 053	899	1 149	1 333	908	1 069	766	819	929	892	1 783	1 969
Ihorombe	545	376	537	702	150	286	446		275	914	1 019	865	1 115	1 299	874	1 135	320	373	483	746	1 749	1 935
Atsimo Atsinanana	688	519	680	745	405	429	109	275		1 057	1 162	1 008	1 258	1 442	1 017	1 178	595	648	758	1 001	1 892	2 078
Atsinanana	369	538	464	587	764	628	948	914	1 057		105	459	939	1 123	698	1 020	1 234	1 287	1 397	1 099	1 573	1 759
Analanjirofo	474	643	569	692	869	733	1 053	1 019	1 162	105		564	1 044	1 228	803	1 125	1 339	1 392	1 502	1 204	1 678	1 864
Alaotra Mangoro	320	489	415	538	715	579	899	865	1 008	459	564		890	1 074	649	971	1 185	1 238	1 348	1 050	1 524	1 710
Boeny	570	739	665	788	965	829	1 149	1 115	1 258	939	1 044	890		474	241	636	1 435	1 488	1 598	1 300	924	1 110
Sofia	754	923	849	972	1 149	1 013	1 333	1 299	1 442	1 123	1 228	1 074	474		425	820	1 619	1 672	1 782	1 484	450	636
Betsiboka	329	498	424	547	724	588	908	874	1 017	698	803	649	241	425		395	1 194	1 247	1 357	1 059	875	1 061
Melaky	651	659	556	433	885	749	1 069	1 135	1 178	1 020	1 125	971	636	820	395		1 357	1 408	1 518	407	1 270	1 456
Atsimo Andrefana	865	696	857	922	470	606	766	320	595	1 234	1 339	1 185	1 435	1 619	1 194	1 357		582	692	1 066	2 069	2 255
Androy	918	749	910	975	523	659	819	373	648	1 287	1 392	1 238	1 488	1 672	1 247	1 408	582		110	1 129	2 122	2 308
Anosy	1 028	859	1 020	1 085	633	769	929	483	758	1 397	1 502	1 348	1 598	1 782	1 357	1 518	692	110		1 239	2 232	2 418
Menabe	730	561	722	787	596	460	892	746	1 001	1 099	1 204	1 050	1 300	1 484	1 059	407	1 066	1 129	1 239		1 934	2 120
Diana	1 204	1 373	1 299	1 422	1 599	1 463	1 783	1 749	1 892	1 573	1 678	1 524	924	450	875	1 270	2 069	2 122	2 232	1 934		448
Sava	1 390	1 559	1 485	1 608	2 003	1 649	1 969	1 935	2 078	1 759	1 864	1 710	1 110	636	1 061	1 456	2 255	2 308	2 418	2 120	448	

B. Adjacent

	Analamanga	Vakinankaratra	Itasy	Bongolava	Haute Matsiatra	Amoron'I Mania	Vatovavy Fitovinany	Ihorombe	Atsimo Atsinanana	Atsinanana	Analanjirofo	Alaotra Mangoro	Boeny	Sofia	Betsiboka	Melaky	Atsimo Andrefana	Androy	Anosy	Menabe	Diana	Sava
Analamanga		1	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
Vakinankaratra	1		1	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0
Itasy	1	1		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bongolava	1	1	1		0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0
Haute Matsiatra	0	0	0	0		1	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0
Amoron'I Mania	0	1	0	0	1		1	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0
Vatovavy Fitovinany	0	0	0	0	1	1		0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Ihorombe	0	0	0	0	1	0	0		1	0	0	0	0	0	0	0	1	0	1	0	0	0
Atsimo Atsinanana	0	0	0	0	1	0	1	1		0	0	0	0	0	0	0	0	0	1	0	0	0
Atsinanana	0	1	0	0	0	1	1	0	0		1	1	0	0	0	0	0	0	0	0	0	0
Analanjirofo	0	0	0	0	0	0	0	0	0	1		1	0	1	0	0	0	0	0	0	0	1
Alaotra Mangoro	1	1	0	0	0	0	0	0	0	1	1		0	1	1	0	0	0	0	0	0	0
Boeny	0	0	0	0	0	0	0	0	0	0	0	0		1	1	1	0	0	0	0	0	0
Sofia	0	0	0	0	0	0	0	0	0	0	1	1	1		1	0	0	0	0	0	1	1
Betsiboka	1	0	0	1	0	0	0	0	0	0	0	1	1	1		1	0	0	0	0	0	0
Melaky	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1		0	0	0	1	0	0
Atsimo Andrefana	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0		1	1	1	0	0
Androy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1		1	0	0	0
Anosy	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1		0	0	0
Menabe	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0		0	0
Diana	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0		1
Sava	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	

Source: Authors (Data from the National Hydrographic and Geographic Institute in Madagascar)
Note: The distance is calculated using the optimal itinerary connecting two regions' capitals.