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Abstract

The dramatic increase in the price of rice and other commodities over the past year has generated new interest in how these markets work and how they can be improved. This paper uses an exceptionally rich data set to test the extent to which markets in Madagascar are integrated across space at different scales of analysis and to explain some of the factors that limit spatial arbitrage and price equalization within a single country. We use rice price data across four quarters of 2000-2001 along with data on transportation costs and infrastructure availability for nearly 1400 communes in Madagascar to examine the extent of market integration at three different spatial scales—sub-regional, regional, and national—and to determine whether non-integration is due to high transfer costs or lack of competition. The results indicate that markets are fairly well integrated at the sub-regional level and that factors such as high crime rates, remoteness, and lack of information are among the factors limiting competition.

1. Introduction

When world rice prices hit record highs in April 2008 (IRRI 2008)—rising 150 percent from December 2007—governments around the world openly raised concerns over food insecurity, increased poverty and, in some cases, the potential for riots and unrest. Although the focus in the media tended to be on the hardships for consumers, many small farmers were actually harmed as well because of the increased cost of fuel, transport and fertilizer and because many of these farmers are actually net purchasers of rice (Fuller 2008). While prices have since fallen somewhat, the crisis increased interest in how commodities markets work and has drawn

attention to the fact that large seasonal price fluctuations and high transport and input costs are the norm for millions of farmers living in areas where markets are poorly integrated.

Well-functioning markets ensure that macro-level economic policies (e.g., with respect to exchange rates, trade, fiscal or monetary policy) change the incentives and constraints faced by micro-level decision-makers. Macro policy commonly becomes ineffective without market transmission of the signals sent by central governments. Similarly, well-functioning markets underpin important opportunities for welfare improvements at micro-level that aggregate into sustainable macro-level growth. For example, without good access to distant markets that can absorb excess local supply, the adoption of more productive agricultural technologies typically leads to a drop in farmgate product prices, erasing the gains from technological change and thereby dampening incentives for farmers to adopt new technologies that can stimulate economic growth. Markets also play a fundamental role in managing risk associated with demand and supply shocks in that well-integrated markets facilitate adjustment in net export flows across space and in storage over time, thereby reducing price variability faced by consumers and producers.

In much of rural Africa and in other low-income areas, however, poor communications and transport infrastructure, limited rule of law, and restricted access to commercial finance, can all sharply limit the degree to which markets function as effectively as textbook models typically assume. A longstanding literature documents both the institutional constraints to market development (see, for example, Platteau 2000; Fafchamps 2004) and the considerable commodity price variability across space and seasons in developing countries, with various empirical tests of market integration suggesting significant and puzzling foregone arbitrage opportunities (Fackler and Goodwin 2001 and Abdulai 2007 offer good reviews).

This paper uses an exceptionally rich data set that includes rice price data across four quarters along with data on transportation costs and infrastructure availability for nearly 1400 communes in Madagascar. This enables us to test not only the extent to which markets are integrated across space, but also to undertake unprecedented comparison of results across different spatial scales of analysis and to explain some of the factors that limit spatial arbitrage and price equalization within a single country. For example, within small geographic sub-regions (*fivondronana*), we find considerable co-movement of rice prices across communes linked by a single, nearby hub periodic market, signaling competitive tradable equilibrium (CTE) with a high degree of price transmission. At the other end of the spatial scale, high interregional marketing costs (due to transport, etc.) dampen price transmission at the national level. Meanwhile, at the intermediate regional level (inter-*fivondronana* market linkages), there appear considerable foregone arbitrage opportunities, i.e., CTE does not hold and price transmission appears poor. This would indicate that policies intended to improve the performance of food markets may need to focus on reducing market intermediation costs (e.g., through main trunk road improvements) at one level of (national) government but on competition policy at another (provincial) level. Such interventions are largely unnecessary at the local level.

The contributions of this paper are fourfold. First, no other study of which we are aware offers the sort of multi-scalar comparative markets analysis we produce. This is important because there can exist different policies at different spatial scales of analysis but little research acknowledges this, much less explicitly explores whether conditions and appropriate policies are the same at local, regional and national scales. Second, most spatial price analyses rely on data from a very small number of locations but a large number of intertemporal observations; hence the widespread use of time series econometric methods in this literature. Yet for many settings, there do not exist time series of adequate duration to undertake rigorous dynamic estimation to underpin important policy choices with respect to markets. We provide what we believe to be the first demonstration of spatial price analysis where the data's variation is primarily in the

cross-sectional dimension, rather than intertemporally. In such cases, commonplace time series estimation methods (e.g., cointegration, error correction models, Granger causality) are infeasible; despite its own limitations, the parity bounds model (PBM) approach is feasible and most appropriate given such data. Third, prior studies invariably impose either the assumption that competitive tradable equilibrium (CTE) always holds – meaning traders always and everywhere earn zero profits at the margin – or that unobserved costs of commerce are constant across space and time, and cannot (or at least do not) check the robustness of results to relaxation of one assumption in favor of the other. The nature of our data and estimator permits us to conduct such a robustness test for the first time. Finally, very few studies attempt to explain observed patterns of price relationships, typically presenting only conclusions with respect to the extent of market integration but not the correlates of those patterns.[3] A central part of this study aims to identify the attributes of jurisdictions where markets perform better or worse relative to the CTE benchmark. The results are intuitive and of direct policy relevance, emphasizing the importance of crime, information flow and physical remoteness on market performance.

The remainder of the paper is organized as follows. The next section briefly reviews the theory and estimation of market integration. Section 3 provides background on markets in Madagascar and section 4 describes the data. Sections 5 and 6 present the results of two approaches to Parity Bounds Model estimation in the presence of unobserved transfer costs to assess the extent of spatial market integration. Section 7 discusses the policy implications of our findings.

2. Theory and empirical testing of competitive spatial equilibrium

The concepts motivating this paper come from basic trade theory dating back to the work of Enke (1951), Samuelson (1952), and Takayama and Judge (1971) on spatial market equilibria (Barrett 2001). If markets are efficient, in the sense of competitive tradable equilibrium (CTE)

[3] Gonzalez-Rivera and Helfand (2001) and Goodwin and Schroeder (1991) are important exceptions.

with zero expected marginal profits to arbitrage, we should expect prices to equilibrate across space accounting for all transfer costs. In particular, we should observe the following relationship between prices in two distinct locations:

$$E\{r_{it}\} \leq r_{jt} + \tau_{ijt} \qquad (1)$$

Where E is the expectations operator, r_{it} is the price of a homogeneous commodity in location i in time t, and τ_{ijt} is the transfer cost of moving commodity from j to i in time t.[4] When prices follow competitive spatial equilibrium condition (1), the nonpositive expected profits to arbitrage leave no attractive opportunities for trade unexploited by marketing intermediaries. If (1) holds with equality, then the product is tradable between markets and the welfare gains from CTE emerge whether or not trade flows actually occur. In the context of spatial market integration, Baulch (1997) refers to the competitive equilibrium condition under tradability (i.e., condition 1 holds with equality) as regime 1.

A second, non-trading or segmented competitive equilibrium also exists in the case of high transfer costs or low price differentials if $E\{|r_{it}-r_{jt}|\} < \tau_{ijt}$, i.e., arbitrage is unprofitable in expectation (Samuelson 1952). Contrary to the regime 1 case, profitable trade should never occur under this segmented competitive equilibrium condition; on average, arbitrageurs would expect to lose money on trade. This is Baulch's regime 2. Finally, in regime 3, $E\{|r_{it}-r_{jt}|\} > \tau_{ijt}$, and there appear to be positive expected returns to intermarket trade, signaling foregone arbitrage opportunities and markets that are not perfectly competitive. Regime 3 can signal either temporary market disequilibrium or an imperfectly competitive equilibrium characterized by positive marginal profits to arbitrage due, for example, to oligopsonistic or oligopolistic behavior or to binding quantitative restrictions on trade (e.g., quotas). Merel, Sexton, and Suzuki (2008)

[4] We define the transfer costs, τ, to be the total market intermediation costs, which include the observed transport cost, T, plus the unobserved costs associated with loading, temporary storage, information search, contract enforcement, various risks, etc. This can include ad valorem components that vary with the volume transacted or the unit price. Equation (1) merely distinguishes between price and transfer cost components, the complexities of which are readily addressed in estimation.

developed a multi-spatial model of trader market power that helps shed light on how transfer costs can affect oligopsonistic behavior and the persistence of regime 3.

This simple characterization of the standard spatial price analysis problem underscores one of the central, but commonly overlooked, challenges in empirical price analysis. The analyst commonly observes prices, but can observe neither all transfer costs (e.g., that portion of τ_{ijt} attributable to price risk, risk of theft or information costs above and beyond recorded transport costs, tariffs, etc.) nor the nature of market equilibrium or disequilibrium. There are two unknowns in relation (1): the operator (<,= or >) relating $E\{r_{it}- r_{jt}\}$ and τ_{ijt}, and the value of τ_{ijt} itself.

Several methods exist for testing market integration empirically, each of which relies on strong assumptions, including about these two unknowns. Barrett (1996a), Baulch (1997) and others find fault with the common practice of studying market integration using only the comovement of prices in time series data. Among other problems, such studies assume τ_{ijt} does not vary over time nor across markets and cannot accommodate interseasonal flow reversals[5] although these are common features of developing country food systems (Barrett 1996a, Fackler and Goodwin 2002).

If we perfectly observed transfer costs in each period, then we could simply count the number of observations falling into each regime to determine the extent of market integration. With more limited information on transfer costs between the relevant markets – and given that some transfer costs (e.g., risk premia) are inherently unobservable – the Parity Bounds Model (PBM) allows us to establish probabilistic limits within which the spatial arbitrage conditions are likely to hold.

[5] Interseasonal flow reversal occurs when a good flows from rural to urban areas at harvest, then back to rural areas again later when prices go up. This can be caused by insufficient storage or processing capacity, local liquidity constraints, or higher risk of theft or political instability in rural areas (as was the case in Madagascar in the early 1990s, see Barrett 1997, 1996b).

The PBM was first described in the agricultural context by Sexton, Kling, and Carman (1991) and then extended by Baulch (1997).[6]

The PBM directly estimates the probability of observing each of the three regimes using the following likelihood function:

$$L = \prod_{t=1}^{T} [\lambda_1 f_t^1 + \lambda_2 f_t^2 + (1-\lambda_1-\lambda_2) f_t^3] \tag{2}$$

where λ_1 and λ_2 are the estimable probabilities of the market being in regimes 1 and 2, respectively. As indicated above, the three regimes are[7]:

Regime 1: Competitive integrated/tradable equilibrium

$$f_t^1 = \frac{1}{\sigma_e} \phi \left[\frac{Y_t - \delta}{\sigma_e} \right] \tag{3}$$

Regime 2: Competitive non-trading/segmented equilibrium

$$f_t^2 = \left[\frac{2}{(\sigma_e^2+\sigma_u^2)^{1/2}} \right] \phi \left[\frac{Y_t - \delta}{(\sigma_e^2+\sigma_u^2)^{1/2}} \right] \left[1 - \Phi \left[\frac{(Y_t - \delta)\, \sigma_u/\sigma_e}{(\sigma_e^2+\sigma_u^2)^{1/2}} \right] \right] \tag{4}$$

Regime 3: Non-competitive equilibrium or disequilibrium

$$f_t^3 = \left[\frac{2}{(\sigma_e^2+\sigma_v^2)^{1/2}} \right] \phi \left[\frac{Y_t - \delta}{(\sigma_e^2+\sigma_v^2)^{1/2}} \right] \left[1 - \Phi \left[\frac{-(Y_t - \delta)\, \sigma_v/\sigma_e}{(\sigma_e^2+\sigma_v^2)^{1/2}} \right] \right] \tag{5}$$

$Y_t = |r_{it} - r_{jt}| - T_{ijt}$ is the apparent gains from arbitrage, where T is the vector of observed transport costs and δ is the unobserved component of the total transfer costs, i.e., $\tau_{ijt} \equiv T_{ijt} + \delta_{ijt}$.[8] The parameters σ_e, σ_v, and σ_u represent the standard deviations of the three error terms, e_t, v_t, and u_t.

[6] PBM has been extended by extended by Barrett and Li (2002) to allow for the incorporation of trade flow information and by Negassa and Myers (2007) to allow for dynamic shifts in regime probabilities in response to exogenous (policy and other) shocks. PBM has been applied in agricultural price analysis by, among others, Fafchamps and Gavian (1996), Park et al. (2002), and Tostao and Brorsen (2005).

[7] Readers interested in more details on the estimator and extensions to it are directed to Baulch (1997), Barrett and Li (2002) or Negassa and Myers (2007).

[8] This differs slightly from Baulch's original formulation, which uses the log form of the price differential and of transport costs and does not allow for the unobserved component of transfer costs. Barrett and Li (2002) introduce the adjustments we use here.

The uncensored, normally distributed error term, e_t, relates to the transfer cost, while v_t, and u_t refer to the half normal error terms outside or inside the parity bounds, respectively. By estimating the frequency with which different communes fall into different regimes within the domain of spatial arbitrage, we can get a probabilistic sense as to how well markets perform different intermediation functions.

One shortcoming of the PBM approach is that the half-normality and normality assumptions on which this estimator relies are inherently arbitrary (Fackler and Goodwin 2001, Barrett and Li 2002, van Campenhout 2007). This objectionable assumption must be weighed against equally arbitrary and empirically indefensible assumptions that underpin alternative time series approaches to spatial price analysis (see Fackler and Goodwin 2001 for a good summary).

Another shortcoming of PBM approaches that has gone unrecognized in the literature to date is that $\delta_{ijt} \equiv \delta$, i.e., unobservable transfer costs are assumed constant across space and time. This is clearly a strong assumption when markets vary geographically and intertemporally in terms of factors like size, access to credit, risk, and transportation infrastructure. Ideally, one could simply replace the unobserved component of transfer cost, δ, in equations (3)-(5) with $\beta_0 + X_{ijt}'\beta$, where β_0 is the constant unobserved cost common to all markets and X_{ijt} is a vector of market characteristics that vary across space and time.[9] In practice, however, the resulting constrained maximum likelihood problem is overparameterized and typically will not converge, and when it (rarely) does appears highly sensitive to arbitrarily chosen starting values.

One must therefore break the problem into two steps. We first predict the total transfer cost by regressing observed intermarket price differentials on observed transfer costs and covariates thought to be associated with unobserved transfer costs. We then use the resulting estimated

[9] The standard PBM approach assumes $\delta = \beta_0$ and $\beta = 0$.

total transfer costs, along with observed prices, in a conventional PBM to estimate the incidence of the three market regimes. The procedure works as follows. In the first step, we estimate

$$\tau_{ijt} \equiv |r_{it}-r_{jt}| = \tau(X_{ijt},T_{ijt}) + \omega_{ijt} \qquad (6)$$

under the strong assumption that the intermarket price differential exactly equals total transfer costs in expectation – i.e., that CTE holds – and then estimate total transfer costs as a function, $\tau(X_{ijt},T_{ijt})$, of observed transport costs and other attributes of one or both locations and time dummies, with a mean zero error, ω_{ijt}. In the second step, we then replace the term $Y_{ijt}-\delta$ in equations (3)-(5) with the estimated returns to arbitrage, $|r_{it}-r_{jt}|-\hat{\tau}_{ijt}$, and proceed with the PBM estimation as before.

The inherent identification problem that distinguishes between the traditional PBM and this latter approach is that one can observe neither all transfer costs nor the nature of market equilibrium (competitive or non-competitive) and thus can only estimate spatial market integration under necessarily-strong simplifying assumptions that restrict one or the other of those features of actual markets. The resulting estimates offer a useful robustness check on actual market conditions, as we shall see.

3. Background on Rice Markets in Madagascar

With a wide range of climates and transportation infrastructure, Madagascar provides an interesting and potentially valuable case study of agricultural prices and markets. Madagascar is a relatively large country—587,000 km^2, roughly the size of France—with a population of about 16 million (INSTAT 2003). It has approximately 6,300 km of paved road and 23,000 km of unpaved road, of which only 8,000 km are considered to be in good or fair condition (World Bank 2002).

Rice is the obvious commodity to study because it is nearly universally grown and consumed, and, more than any other good in Madagascar, its price and price variability have an enormous impact on welfare (Barrett and Dorosh 1996). Rice accounts for approximately 44 per cent of land under cultivation and nearly 50 per cent of caloric intake (FAO 1998). Yet most farmers are actually net buyers of rice (Barrett and Dorosh 1996; Minten and Barrett 2008). Nationally representative household survey data collected the same year as the data we use shows that virtually everyone participates in rice markets in Madagascar. Just over two-thirds of the population were net rice buyers, and just over one-quarter were net rice sellers, with one-third of the rice farming subpopulation both buying and selling as many liquidity-constrained smallholders sell some rice at harvest at low prices and buy rice later in the year at high prices (Minten and Barrett 2008).

The government of Madagascar was heavily involved in the rice market and had a legal monopsony on the purchase of rice for much of the 1970s and early 1980s. The resulting downward pressure on rice producer prices caused stagnation in rice production and a huge rice import bill, and ultimately pushed the government to take steps toward liberalization in 1983 that continued throughout the 1980s and into the 1990s (Barrett 1994). However, policy reform may not have been sufficient to foster competitive markets. Total rice production increased little in the country during the 1990s. Yields remained stagnant and well below world average yields (IRRI 2008). In some cases it appears that politically connected families ran regional monopsonies. A survey in 1990 revealed that few rice farmers had access to more than one collector, the initial marketing intermediary who buys crop at farmgate and then resells for a miller or wholesaler (Barrett 1994).

Market liberalization should have enabled traders to enter the rice market to take advantage of new opportunities. However, Barrett (1997) found that barriers to entry, such as lack of credit and state connections, limited competition in the areas of wholesale crop collection, interregional

transport and interseasonal storage. Subcollection (local collection for sale to a wholesaler), ox-cart transport and casual retailing had low barriers to entry, but appeared to be very low expected profit activities taken up primarily by those needing additional income in hard times. Thus imperfect competition appeared to persist after liberalization within certain segments of the marketing channel, notably those that involved longer haul or longer term operations, rather than purely local, contemporaneous transport or transformation services.

The means used to transport rice vary widely. While motorized transport – in the form of private lorries as well as public bush taxi and bus services – is the most commonly used means, ox-carts, hand-drawn carts, and porters are also used. Although the presence and conditions of roads largely determines the choice of transport, small retailers are more likely to use more expensive non-motorized means of transport even where motorized transport exists. Fafchamps et al. (2003) do not, however, find evidence of increasing returns to trade in Madagascar, not even within the more restricted domain of transport costs.

Traders are highly localized. In a study of traders conducted in 1996-97, only 8.8 per cent of wholesalers made purchases from areas more than 100 km away (Mendoza and Randrianarisoa 1998). Traders cited numerous police checkpoints, high transportation costs, and informal regulations on the movement of rice as the main obstacles to expanded interregional trade. The use of formal and informal sources of credit is rare among traders. Eighty-nine per cent of traders used their own money to support current operations and 85 per cent used their own money to finance new investments. Among those who did borrow to finance investment, only 13 per cent borrowed from banks. Large traders were more likely to borrow from banks than smaller ones. Traders most often used informal sources to obtain market information and the use of telephones and fax machines (even where available) was rare (Mendoza and Randrianarisoa 1998).

Fafchamps and Minten (2001) find that incidents of theft and contractual breach are low among traders, but that this is due to active avoidance of exposure to risk rather than low ex-ante risk or ex-post enforcement of laws. Traders incur high transfer costs in order to guard against theft through such actions as sleeping on rice stocks, minimizing the number of hired workers, and avoiding overnight storage. Furthermore, competition does not appear to improve the efficiency of markets as larger, more profitable firms do not use their advantage to lower prices and drive out smaller firms. Social networks are an important resource for Malagasy traders, and personal relationships with other traders and lenders have a positive effect on efficiency (Fafchamps and Minten 2002).

4. Data and descriptive statistics

This paper takes advantage of a unique data set from Madagascar that includes rice prices and transportation costs for nearly all of the 1394 communes (districts) in the country for four calendar quarters. The 2001 commune census was conducted in collaboration between Cornell University and the Malagasy agricultural research institute (FOFIFA) over a three-month period in 2001. The survey was conducted at the commune's administrative centre in a single visit. The remoteness of some communes and the general lack of national data on certain subjects meant that little was previously known about the spatial distribution of public goods and services, prices, or economic activity prior to this study. Most of the commune census questions, such as those concerning local prices over the previous four quarters, transportation costs, access to various goods and services, major economic activities, ethnic composition of the commune, and community perceptions of existing conditions, were answered by a focus group composed of residents of the commune.

The commune is the smallest administrative unit with direct representation and/or funding from the central or provincial government in Madagascar. The mean (standard deviation) area of the

communes is 426 (514) square kilometers and population is 8,800 (20,425) residents. A dozen or so physically contiguous communes are grouped to form the next highest administrative unit, the *fivondronana*. The *chef-lieu*, or seat, of the *fivondronana* is usually the largest town and the centre of commerce in the area. The 111 *fivondronana* are further grouped into the six provinces of Madagascar. Figure 1 shows the provinces, *fivondronana*, communes and the nine major cities of Madagascar.

The administrative units described above form the basis of the three market scales used later in the empirical analysis. The capital, Antananarivo, is centre of the national level market. The sub-regional and regional scales correspond roughly, but not exactly, to the administrative boundaries of *fivondronana* and provinces, respectively. The six provincial capitals plus three other major cities (Morondava, Fort-Dauphin, and Antsirabe) are the hubs that define the regional markets.[10] The transport section of the commune census allowed the respondents to choose which of the nine major cities commune residents travel to most frequently. This city is usually, but not necessarily, the provincial capital or the nearest city. The commune census collected data on transport costs of 50 kg of rice to this city and to the capital for both the rainy season (calendar quarters 4 and 1) and the dry season (quarters 2 and 3).[11]

Because the sub-regional towns were identified as the first *chef-lieu de fivondronana* passed in transit to the major city, the sub-regional town does not necessarily correspond to the *fivondronana* to which the commune belongs. Out of 111 *fivondronana* in the country, 105 are

[10] Two of these cities, Morondava and Fort Dauphin, are extremely difficult to get to from their provincial capital, Toliara, and little trade occurs between them. The third city, Antsirabe, in the province of the capital city, Antananarivo, is the second largest city in the country and is an important area for agricultural production and processing.

[11] The commune census did not collect information on transporting rice from the commune to the *chef-lieu de fivondronana*. However, the commune census did include detailed questions on the costs of transportation per *person* for each step of the trip from the commune to the nearest major city. In order to estimate the transport cost for rice at the sub-regional level, we first took the transportation cost per person from the commune to the first *chef-lieu de fivondronana* passed on the way to the major city. Then, the rice transport costs at the sub-region are calculated by multiplying the fraction of the total human transportation cost incurred in traveling to the sub-region by the regional rice transport cost.

used by at least one commune in transit to the major city. Thus these 105 form the group of sub-regional towns. While our definition of the sub-regional towns is data driven, it is not unreasonable to assume that the *chef-lieu de fivondronana* that one must pass through to get to a larger city is the town with which the commune trades. Periodic markets are ubiquitous at spots where travellers change vehicles or modes of transport. Without detailed information on actual flows of goods, this choice is less arbitrary, given the economic geography of trade in Madagascar, than strictly using administrative boundaries.

Table 1 presents some selected descriptive statistics from the commune census as well as the 1993 population census and income data from the most recent World Bank poverty map (Mistiaen et al. 2002). The data are split into rural and city/town communes, where the latter refers to the 111 communes containing the city or town serving as the *chef-lieu de fivondronana*. These communes are not urban in the sense that they may have significant land outside the town or city devoted to agriculture, but, as mentioned above, can be thought of as sub-regional market hubs. The city/town communes tend to have higher mean incomes, lower poverty rates and percent of population in agriculture, and higher literacy rates and populations. Rural communes are slightly more likely to be classified as *zone rouge*, an official government designation given to high crime areas.

Turning to the rice prices in Table 2, the second calendar quarter (April to June) is the main harvest period in most regions of the country and thus the second and third quarters tend to have the lowest rice prices. Notice that the rural communes have lower average rice prices than towns in the second and third quarters (April to September), but higher prices in the fourth and first quarters (October to March). This seems to suggest seasonal flow reversals, in which producing areas export rice in the post-harvest quarters and import in the two pre-harvest quarters, leading to greater interseasonal price variability in rural areas, as has been observed previously (Barrett 1996b). Figure 2 shows the median and span of the rice price across the quarters for all

communes and figure 3 shows the median and span of the price differences between the city (regional) price and the rural price.

The correlation of prices across time, space, and form (Table 3) provides further preliminary evidence of the state of markets in Madagascar. The pre-harvest, low season rice price (January-March) is not highly correlated with the price of the harvest season that follows (April-June). As we would expect in fragmented markets, the commune price is more highly correlated with the sub-regional price than with the regional price. The price of paddy, or unmilled rice, is highly correlated with the (milled) rice price in the second and third quarters, but there is likely little rice left in paddy form by the fourth and first quarters, explaining much lower correlations in those periods. The high variability in the correlation between imported rice and local rice is striking, yet also consistent with the fact that there is low demand for imported rice in the post-harvest (second and third) quarters.

5. Estimating the frequency of competitive tradable equilibrium at multiple spatial scales

The very short time series available necessarily preclude using conventional time series price analysis methods (e.g., cointegration or error correction models of various sorts).[12] Its methodological weaknesses notwithstanding, the PBM approach is therefore the only feasible method for analysts confronted with data that vary more in cross-section than in time series. We proceed initially under the standard PBM assumption of constant unobserved transfer costs before moving in the next section to apply our new two-step approach to relaxing the constant unobserved transfer costs assumption in favor of assuming constant competitive tradable equilibrium.

[12] See Abdulai (2000, 2006) for nice examples of time series methods applied to sub-Saharan African agriculture. Abdulai (2007) surveys the relevant literature as well.

Using these price and transport cost data, we now turn to estimating the frequency of competitive tradable spatial equilibrium at the three different spatial scales. The sub-regional level market scale uses the absolute value of the difference between the commune price, r_{it}, and the sub-regional town's price, r_{jt}, in the calculation of arbitrage opportunities. The regional level scale price, r_{jt}, reflects the price in the nearest of the country's major cities. The national scale analysis uses the period-specific rice price in the capital, Antananarivo. We have four quarterly observations per commune, roughly 5,000 observations at each spatial scale, to estimate the probabilities associated with each market regime at each of the three spatial scales (Table 4).[13]

Striking differences emerge at different scales of analysis. High transportation costs result in little incentive to trade at the national level, where we estimate that 83 per cent of observations fall into the unprofitable trade regime 2. Widespread segmented competitive equilibrium suggests that national level policy transmits poorly across the island nation through rice markets and that welfare losses at national scale arise primarily due to the high costs of commerce, not due to market power by traders. This is consistent with other recent studies that find considerable isolation of parts of rural Madagascar entail significant welfare costs (Razafindravonona et al. 2001, Minten and Barrett 2008, Stifel and Minten 2008). In contrast, there appear to be large potential gains to market entry at the regional level, as 63 per cent of communes fall into regime 3 (not in competitive spatial equilibrium). Only six per cent of communes are in CTE and 31 per cent in segmented competitive equilibrium at regional scale. Again, it is impossible to distinguish between widespread, frequent disequilibrium and imperfect competition in these data with this estimation method. But the empirical evidence is consistent with the oft-heard claim that traders exert market power at this intermediate scale of analysis.

[13] We used the Davidon-Fletcher-Powell algorithm to solve the maximum likelihood problem (equation 5). Local maxima were compared across a range of starting values to find the global maximum at each spatial scale. The sub-regional towns and regional cities are omitted from the analyses at all scales since these are the presumed destinations of rice.

Markets are far more frequently in CTE at the sub-regional level than at more aggregate scales of analysis. An estimated 69 per cent of communes are in CTE at the most local, sub-regional level. Yet even at this highly localized scale, ten per cent are in regime 3, suggesting that disequilibrium or imperfect competition occur even locally. Taken together, these results imply that the government needs to work on reducing market intermediation costs at the national level, but should encourage competition and market entry at the regional level and largely leave the most local level markets alone, as they appear to be working reasonably well.

Under the strong maintained hypothesis of the standard PBM model that unobserved transfer costs are constant across market pairs and seasons, the unobserved component of market intermediation costs appears quite modest. The estimates for the unobserved transfer cost parameter, δ, range from 0.4 per cent of the rice price at the sub-regional level, to 0.8 per cent at national level, up only to 1.3 per cent at regional level, and are consistently dwarfed by the observed transport cost component under this formulation. As we see in the next section, however, the assumption of constant unobserved transfer costs may be indefensibly strong.

Having estimated the probability that different market conditions – tradable (regime 1) or segmented (regime 2) competitive equilibrium or disequilibrium or imperfect competition (regime 3) – occur, the next natural policy question is: what affects the likelihood that a given commune falls into a particular (dis)equilibrium regime? Osborne (2005), for example, finds marked differences in trader competition across different locations in Ethiopia, with the larger market with better communications more likely to enjoy competitive tradable equilibrium than smaller markets less well integrated into broader commercial networks.

We can try to explain the incidence of the various regimes by using a multinomial logit model with the dependent variable taking on values 1, 2, or 3, corresponding to the regime we predict

the commune falls into in that period according to the PBM estimates.[14] For brevity, we include the results for the sub-regional level only (Table 5); results at the more aggregate level are similar and available by request. Regime 1 (tradable competitive equilibrium) is the comparison group. Sub-regional fixed effects were included in the estimation, but are not reported in Table 5.[15]

Several interesting and intuitive patterns emerge. High crime areas are more likely to be in regime 3 (disequilibrium or non-competitive equilibrium) than in competitive equilibrium. Traders are clearly reluctant to engage in trade in more dangerous areas and, as a result, it would seem that intermarket price differences are higher not necessarily because of higher risk premia – which are assumed away in this formulation, but will be permitted in the next section – but perhaps because of less competition or more frequent instances of profitable disequilibrium. Communes closer to the town are more likely to be in CTE and those farther away are statistically significantly more likely to be in regimes 2 or 3, especially the former, reflecting segmented equilibrium. The latter result may indicate that information concerning arbitrage opportunities in remote areas does not reach a sufficient number of traders, as we control directly for transport costs in estimation. Higher income communes are more likely to be in CTE, although it is impossible to establish the direction of causality in that relation. Consistent with previous studies showing a strong link between isolation and poverty in Madagascar (Razafindravonona et al. 2001, Stifel and Minten 2008), the strong and statistically significant negative effect of income on the likelihood of falling into regime 2 or 3 suggests that poorer communes are more likely to suffer segmented markets, imperfect competition or market disequilibrium. The quarter-specific dummies show that, relative to the January-March period, communes are statistically significantly less likely to be in regime 3 in the July-September and

[14] To place observations in a particular regime, we ordered the data by the spatial arbitrage condition ($|r_{it}-r_{jt}|-T_{ijt}$) and assigned regimes based on the percent of observations estimated to be in a particular regime. It is not possible to recover the actual probability of being integrated associated with an individual observation.
[15] The estimation was repeated without the sub-regional level fixed effects. The results are quite consistent with those presented here and are available upon request.

October-December periods. Most of the foregone opportunities for profitable arbitrage thus appear to occur just prior to and during the main harvest period.

The results of the analysis of spatial market integration under the assumption of uniform unobserved transfer costs indicate that markets are fairly well integrated at the sub-regional level and that factors such as high crime, poverty and remoteness are significantly associated with limited tradability and competition. At the regional level, only a small percentage of communes are competitively integrated and most communes appear to be in disequilibrium or an imperfectly competitive equilibrium. At the national level, high market intermediation costs – chiefly transport costs – are the main obstacle to integrated markets. The striking differences in market functioning at the three different scales and the existence of non-competitive equilibria or disequilibria imply that policies such as improving transportation infrastructure to reduce transport costs – a central plank of the current government's development strategy – are necessary for improved national-scale market integration, but likely insufficient to ensure the emergence of competitively integrated markets at regional scale. Anti-crime policies would seem to play an important role as well in facilitating more efficient market performance throughout the island.

6. Spatial price analysis allowing for unobserved transfer costs

The previous section presented the estimated market regime probabilities under the standard, strong assumption of constant unobserved transfer costs across markets and seasons. In this section we present an alternative approach. The fundamental identification problem faced in markets analysis is that there always exist (at least) two unknowns: unobserved transfer costs and market conditions – i.e., in or out of competitive equilibrium and with or without the zero marginal profits to arbitrage constraint binding. One can estimate unobserved transfer costs by

imposing the assumption that competitive equilibrium holds with the intermarket price differential exactly equal to the total (observed plus unobserved) transfer costs. Or one can estimate the frequency distribution of different market regimes, following the standard PBM maintained hypothesis that unobserved transfer costs are constant across all observational units.

It is effectively impossible, however, to accommodate simultaneously the twin possibilities that markets are not constantly in CTE and that there exist variable unobserved transfer costs. Intuitively, the problem is that the same factor(s) – e.g., high crime rates, remoteness, poor communications systems – may increase both unobserved costs and the likelihood of imperfect competition. The best one can do is to do price analysis under each assumption, using the modified PBM introduced earlier, and then compare results as a robustness check.

Recall from above that our modified approach first uses the CTE assumption to estimate the unobserved transfer costs by regressing the absolute value of the intermarket price difference on the observed transportation cost and other market characteristics.[16] This gives us an estimate of total transfer cost, with which we can then modify the PBM as described earlier and reestimate regime probabilities, now allowing for variation in unobserved transfer costs. The obvious disadvantage of this approach is that it imposes the maintained hypothesis that price differences are fully explainable by the set of regressors such that deviations from the first stage regression are random.[17] It is important to recognize that this will tend to result in higher estimates of regime 1 – the only regime for which condition (1) holds with equality – and thus lower estimates of regime 2 and/or 3 frequencies. By contrast, the traditional PBM approach generates

[16] We estimate the first stage using ordinary least squares. However, because 15-17% of the price differences equal zero, we also tried a tobit estimator and found that this did not change our qualitative results at all. Details are available from the authors by request.
[17] This assumption is common in the literature. See, for example, Fackler and Tastan (2008).

downwardly biased estimates of regime 1 frequency if variable unobserved transfer costs appear as large deviations of intermarket price differences from observed plus estimated constant unobserved transfer costs. Hence the usefulness of comparing results generated by these two different sets of assumptions and resulting biases.

Table 6 reports the unobserved (total) transfer cost estimation. While observed transportation costs have an effect that is positive and statistically significantly different from zero, that effect is also statistically significantly much less than one at all of the spatial scales. This result is quite striking. At each scale of analysis, intermarket price differentials appear to increase by only 21-26 per cent of any increase in transport costs. This almost surely reflects the considerable market segmentation that exists in a large country with rugged topography, poor roads and high transport costs – i.e., local, autarkic market equilibria limit spatial price differences associated with high marketing costs – and thereby underscores our concern about the effect of imposing CTE in estimating variable unobserved transport costs. Price increases less than one-for-one with observed intermediation costs signal violations of the law of one price, which is based on the CTE assumption.

The regression results indicating the correlates of unobserved transfer costs are generally quite intuitive. Not having access to motorized transport tends to increase the transfer cost – probably due to higher unobserved labor and delay costs – even controlling for transport costs, although the effect is not statistically significant at the subregional scale. Radio reception is associated with reduced arbitrage costs at the subregional level, but not at other scales. This is possibly because regional radio only provides regional information or because, even with adequate information regarding prices and costs, local traders are unable to make the larger investments to

take advantage of opportunities at greater distances. Having a bush taxi stop in the commune tends to reduce the transfer costs, but the effect is only statistically significant at the national level. As one might expect, high crime increases the cost at all spatial scales, but the effect is greatest at the subregional level, amounting to more than 4 per cent of market prices.

Consistent with the previous, counterintuitive result from the multinomial logit estimations, local banks are associated with higher costs and this effect is statistically significant at the regional level. Access to electricity tends to reduce transfer cost, possibly reflecting lower costs of processing and storage. The major city dummy variables show that costs in areas around the isolated cities of Fort Dauphin (omitted) and Antsiranana are higher than other areas as are costs in the port cities of Mahajanga and Toamasina. The latter results are particularly interesting given that Mahajanga is a major rice producing area. The quarter specific effects are also quite striking. Estimated transfer costs during the harvest period (2) are higher at all spatial scales, while the costs drop significantly in the third quarter. This might reflect the high demand for transport capacity in the immediate post-harvest period. Transport demand falls in the third quarter after much of the rice has been moved and then increases again in the low season as rice starts to move back to rural communes, again signaling interseasonal flow reversals.

Compared to the results of the standard PBM estimation (Table 4), we see very little change in the regime probabilities at the sub-regional level. In both cases, roughly 70 per cent of communes appear to be in CTE (regime 1), with approximately 22 per cent in the non-trading regime 2 and 10 per cent or less falling into the non-competitive equilibrium. The result that local, sub-regional markets are typically in CTE thus seems quite robust.

By contrast, the results at the regional and national scales change significantly. At the regional and national levels, regimes 3 and 2, respectively, dominated in the original estimation, but much of this, as expected, is shifted to regime 1 when one tries to accommodate variable unobserved transfer costs by imposing the first-stage assumption that condition (1) holds with equality. Casually taking the λ_1 estimates from the two approaches as bounds on the true frequency, CTE occurs in 6-52 per cent of cases at regional level and 13-60 per cent of cases at national scale, rather large ranges. Meanwhile, at regional and national levels, 31-43 per cent and 36-83 per cent of cases, respectively, fall into the segmented equilibrium regime. Segmented equilibria are commonplace at these more aggregate scales of analysis, occurring at least one-third of the time and reflecting the need for interventions – such as road improvements – to bring down the costs of spatial arbitrage. The possibility of non-competitive equilibrium seems modest at sub-regional and national levels, with frequency estimates ranging only from 7-10 per cent in the former case and 4 per cent under both methods at national scale. But at regional scale, the large range of estimates for the λ_3 parameter – 5-63 per cent – makes it difficult to establish the frequency of non-competitive equilibrium or disequilibrium. If there exist competition policy question in Malagasy rice markets, they seem relatively concentrated at this regional, intra-provincial level of trade.

Observed transfer costs do a relatively good job at explaining price differences at the sub-regional scale under competitive equilibrium, hence the strong consistency of results across the two methods. But in a large share of cases, the standard assumption of competitive, tradable spatial market equilibrium does not hold beyond the local level in Malagasy rice markets. Segmented competitive equilibrium associated with high costs of market intermediation is widespread at regional and national levels. Meanwhile, non-competitive equilibria appear rare at

sub-regional and national levels, with unstable parameter estimates at regional level leaving open the question of whether there is adequate competition among traders at that spatial scale of analysis.

7. Conclusions

Competitive, tradable markets are crucial to the process of economic development. Macro-level policies rely on markets to transmit price signals to affect micro-level decision-makers, yet these signals cannot be transmitted or are transmitted unevenly across space and time when markets are not competitively integrated with possibilities for trade. Similarly, at the micro-level, households may be unable to take advantage of potentially welfare-improving agricultural technologies when the local markets must absorb increases in supply, thereby dampening profit incentives to technology adoption. Moreover, by reducing price variability, competitively integrated markets also play a crucial role in dampening the effects of localized and temporary demand and supply shocks and in reducing seasonal poverty and food insecurity.

However, spatial price analysis frequently fails to account for the complexity of integration across space. Agricultural markets in developing countries, in particular, may be segmented or integrated, competitive or non-competitive, to varying degrees at different spatial scales, with significant unobservable costs of commerce that vary across space and time. This paper illustrates this complexity through examination of the extent of integration of rice markets in Madagascar at three spatial scales and across periods using rice price data from a 2001 census of nearly 1400 communes. In so doing, we offer a unique demonstration of how one can perform spatial price analysis using data that vary more in cross-section than in time series and we introduce a new approach to testing the robustness of parity bounds model estimates to relaxation of the standard assumption of constant unobserved transfer costs.

Our analysis shows that Malagasy rice markets are fairly well integrated spatially at the sub-regional level, where nearly 70 per cent of communes appear to be in CTE. Even without significant public provision of supporting institutional or physical infrastructure, local level trade appears to operate in an efficient, competitive manner in the vast majority of places and periods. This should serve as a caution against any reimposition of heavy-handed state interference in food marketing in rural Madagascar, as was the case prior to mid-1980s reforms (Barrett 1994).

By contrast, markets at national and regional (provincial) levels are far less commonly in CTE. Thus in order to get food markets operating efficiently at larger scales, some sort of public action may be necessary. Our empirical analysis offers some insights as to where to target such interventions. At national scale especially, the low frequency of CTE largely reflects prohibitively high transport costs that force segmented, competitive equilibria. At the regional level, however, the lack of contemporaneous competitive spatial integration may be due to the existence of excess rents to spatial arbitrage, rather than to non-profitable arbitrage; our results on this particular question are ambiguous and demonstrate the sensitivity of empirical findings on such questions to (often latent) modeling assumptions.

Reducing transportation costs is clearly an important policy priority if rural rice producers — who comprise a majority of Madagascar's poor — are to enjoy improved market access. The government of Madagascar seems to recognize this as it has embarked on a massive transportation infrastructure project (World Bank 2003). However, reducing transportation costs is necessary, but perhaps not sufficient for better integration of markets if lack of competition allows excess rents to persist. This may be a concern at the regional level in Malagasy rice markets. Moreover, crime has a notable, large effect in both driving up intermarket price differences, although it is difficult to determine whether this influences the unobserved costs of commerce, the likelihood that a commune faces non-competitive market equilibria, or both.

Because markets are highly fragmented in Madagascar, both macro-level policies and micro-level development projects will likely not have the intended effects and some standard methods for analysing market integration may not be suitable. Integrating markets through reducing high transport costs and crime and by encouraging competition (at the regional level) needs to be a top priority for the government. However, this will clearly take years and considerable resources. In the meantime, policy-makers need to think creatively about how they can take advantage of well-integrated sub-regional markets.

Table 1 Selected commune characteristics*

	Rural	Town/city	Total
Mean income of commune 1993 (Fmg)[18]	297,756	434,391	307,404
	(86,389)	(295,391)	(119,417
Poverty rate (percent of households below poverty line)	75	60	74
	(0.13)	(0.19)	(0.14)
Literacy rate	54.43	71.10	55.60
	(23.64)	(21.10)	(23.85)
Population total 1993	7443.78	26087.32	8750.11
	(4754.16)	(75280.57)	(20898.70)
Percent working in agriculture 1993	58.84	35.54	57.12
	(17.15)	(21.62)	(18.54)
Travel time to nearest major city (hrs)	19.60	17.16	19.43
	(24.03)	(21.79)	(23.88)
Distance to nearest major city (km)	264.90	293.95	266.92
	(262.37)	(313.44)	(266.21)
Percent of communes:			
in which rice is a major crop	70.1	57.6	69.3
in which vanilla is a major crop	6.8	7.6	6.9
in which coffee is a major crop	14.4	7.6	13.9
in which maize is a major crop	10.1	7.6	9.9
in which walking required to leave commune	30.3	3.3	28.4
with a *Route Nationale* passing through it	29.0	82.6	32.7
with a wholesaler	7.8	68.5	12.0
with a mechanical rice mill	38.7	73.9	41.1
classified as *zone rouge*, or high crime zone	30.2	25.0	29.8
with a commercial bank	3.2	59.8	7.1
with radio reception	46.1	76.1	48.2
with access to imported rice	55.2	76.1	56.7

*Town/city refers to the 105 communes whose main towns or cities are *chef-lieu de fivondronana,* or sub-region, the others are classified as rural. Standard deviations are in parentheses

[18] $1≈6,000 Fmg in 2001

Table 2 Mean (standard deviation of) rice prices and transport costs

	Rural	Town/city	Total
Rice price Oct-Dec 2000 (Fmg/kg)	2,525.81	2,468.26	2,521.78
	(1,024.26)	(487.42)	(996.13)
Rice price Jan-March 2001 (Fmg/kg)	2,558.69	2,517.15	2,555.77
	(979.28)	(691.55)	(961.77)
Rice price April-June 2001 (Fmg/kg)	1,780.85	2,156.88	1,807.18
	(982.43)	(2,113.64)	(1,102.89)
Rice price July-Sept 2001 (Fmg/kg)	1,953.81	2,012.50	1,957.92
	(520.41)	(402.13)	(513.11)
Percentage change in rice price	85.40	64.73	83.96
(from min to max across four quarters)	(67.10)	(46.47)	(66.06)
Transport cost to major city (Fmg/kg)	319.09	253.10	314.49
	(414.52)	(259.09)	(405.90)

Table 3. Correlation coefficients

Commune Rice Price	Oct-Dec 2000	Jan-March 2001	April-June 2001	July-Sept 2001
Jan-March	0.78			
April-June	0.11	0.13		
July-Sept	0.50	0.38	0.26	
Quarterly paddy price	0.42	0.63	0.79	0.74
Quarterly imported rice price	0.92	0.91	0.16	0.26
Sub-region price	0.20	0.44	0.54	0.50
Region price	0.19	0.38	0.21	0.42

Table 4. Spatial PBM estimation results

	Sub-region		**Region**		**National**	
	Coeff.	Std Error	Coeff.	Std Error	Coeff.	Std Error
$\lambda 1$ (Regime1)	0.689	0.01849	0.055	0.0140	0.128	0.1911
$\lambda 2$ (Regime 2)	0.215	0.01367	0.311	0.0225	0.830	0.8296
$\lambda 3$ (Regime3)	0.096		0.634		0.043	
σ_E	1.512	0.0372	1.530	0.1158	0.025	0.0368
σ_U	8.623	0.0132	5.989	0.0289	3.894	0.0084
σ_V	4.39	0.0317	1.003	0.1911	0.241	0.0230
δ (unobserved costs, FMG/kg)	8.257	0.1644	27.619	0.1321	18.238	0.1804
N	4930		5070		5070	
Chi-squared	680,941		814,056		1,100,887	
P(Chi-sq > value)	0.000		0.000		0.000	

Table 5 Explaining regime incidence at the sub-regional level

Multinomial logit	**Regime 2**		**Regime 3**	
with sub region fixed effects	**(Segmented)**		**(Non-competitive)**	
Regime 1 is comparison group	dy/dx.	t-statistic	dy/dx	t-statistic
High crime area (dummy)	-0.006	-0.750	**0.002**	**2.850**
Bank (dummy)	-0.003	-0.170	**0.003**	**1.720**
Same ethnic group as town (dummy)	0.006	0.440	**0.002**	**2.210**
Travel time (log of hrs) to town	**0.037**	**10.260**	**0.0005**	**2.690**
No motorized transport (dummy)	-0.006	-0.640	**0.003**	**3.070**
Mean income (log of Fmg)	-0.022	-1.250	**-0.007**	**-5.150**
Population (log)	-0.009	-0.700	0.0001	1.330
Percent working in agriculture	-0.0001	-1.310	-0.00002	-0.330
Radio reception (dummy)	0.007	0.850	**-0.001**	**-1.920**
April-June (dummy)	-0.014	-1.440	0.0003	0.420
July-September (dummy)	**0.024**	**2.440**	**-0.004**	**-6.990**
October-December (dummy)	**0.032**	**3.240**	**-0.004**	**-6.960**
N=	4089			
χ^2=	1104			
Pseudo R^2=	0.164			

Table 6 Parameterization of Unobserved Transfer Cost

Estimator is OLS	Subregion		Region		National	
	Coef.	**t**	**Coef.**	**t**	**Coef.**	**t**
Observed transportation cost	**0.23**	**4.11**	**0.21**	**8.25**	**0.26**	**10.83**
No motorized transport (dummy)	43.74	1.43	**97.77**	**3.84**	**67.38**	**2.67**
Radio reception (dummy)	**-72.32**	**-2.91**	19.70	0.89	23.58	1.07
Motorized transport stop (dummy)	-0.39	-0.57	-1.11	-1.82	**-1.39**	**-2.28**
High crime area (dummy)	**93.24**	**3.61**	**62.96**	**2.67**	**48.95**	**2.08**
Bank (dummy)	85.71	1.41	**107.22**	**2.41**	58.71	1.32
Population	-2.09	-0.1	20.64	1.10	7.97	0.42
Percent of population with electricity	-3.56	-1.66	**-5.77**	**-3.29**	**-4.74**	**-2.71**
Tana	**-293.26**	**-5.44**	**-186.04**	**-3.53**	102.29	1.91
Fia	**-301.67**	**-5.37**	**-285.04**	**-5.24**	87.17	1.59
Tamatave	-27.14	-0.44	-98.59	-1.66	**120.11**	**2.05**
Toliara	**-266.27**	**-4.34**	**-127.09**	**-2.12**	-49.91	-0.83
Mahajanga	-50.49	-0.88	-64.59	-1.17	107.54	1.94
Diego	-33.40	-0.49	82.93	1.28	**173.53**	**2.68**
Antsirabe	**-327.98**	**-4.83**	-295.84	-4.5	-4.16	-0.06
Morondava	**-176.59**	**-2.14**	-118.63	-1.54	100.70	1.32
Quarter 1	12.27	0.39	35.55	1.24	47.32	1.65
Quarter 2	**95.46**	**3.01**	**165.08**	**5.73**	**197.80**	**6.88**
Quarter 3	**-183.08**	**-5.77**	**-126.59**	**-4.40**	**-98.38**	**-3.42**
Constant	**670.94**	**3.57**	**344.91**	**1.98**	**149.35**	**0.85**
Number of obs	3934		4994		4994	
R-squared	0.0681		0.0695		0.064	
PBM estimation						
$\lambda 1$ (Regime1)	0.708	1.863	0.521	10.772	0.598	21.280
$\lambda 2$ (Regime 2)	0.224	1.170	0.433	8.937	0.360	13.171
$\lambda 3$ (Regime3)	0.068		0.047		0.043	
σ_E	1202	6.92	365	40.40	324	51.57
σ_U	1133	1.35	345	9.06	416	16.31
σ_V	1154	2.14	1019	24.31	1164	23.04
Chi-squared	87,958		80,958		80,435	
P(Chi-sq > value)	0.000		0.000		0.000	

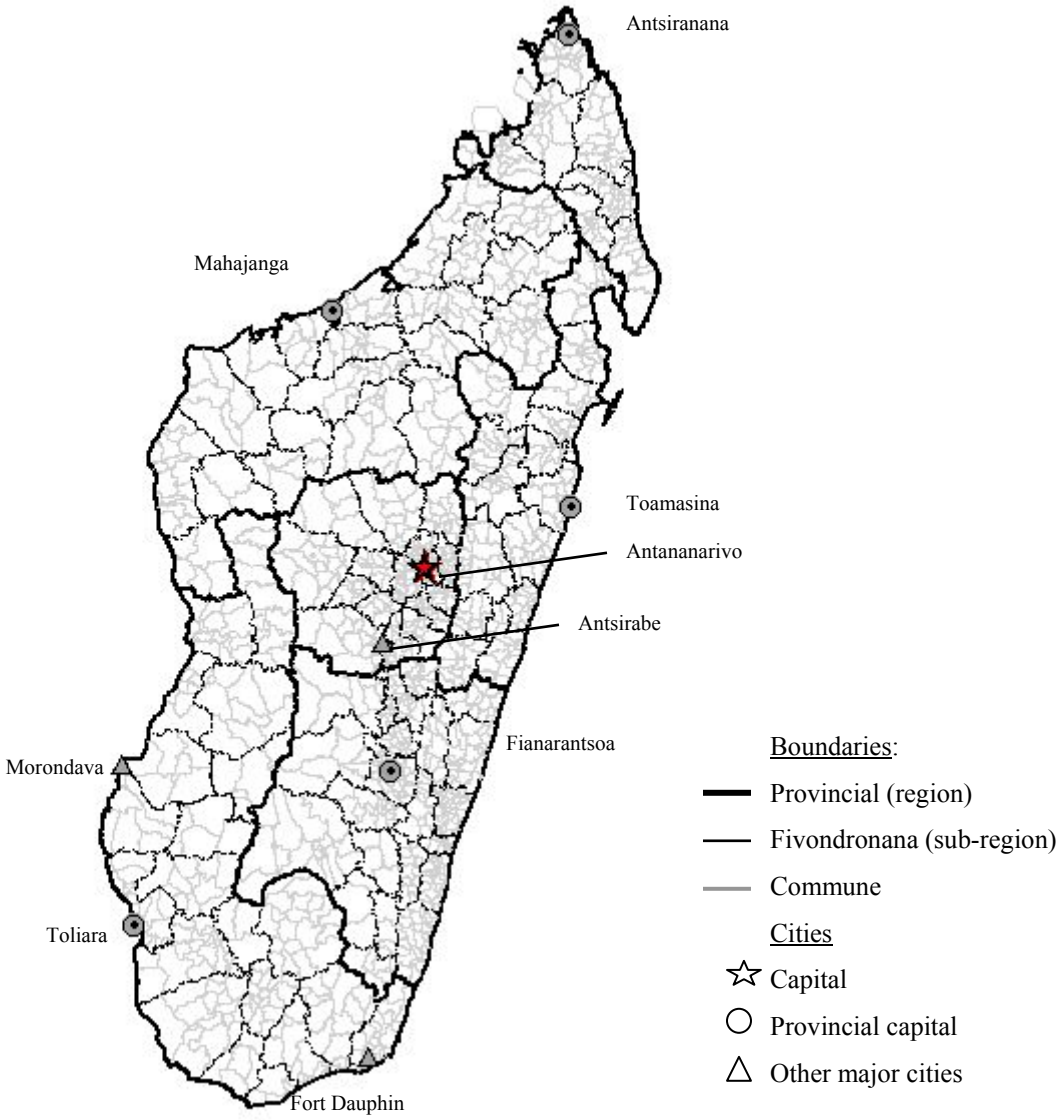

Figure 1. Administrative boundaries and major cities of Madagascar

Figure 2. Rice price by quarter
(Spans are trimmed at the 5th and 95th percentiles)

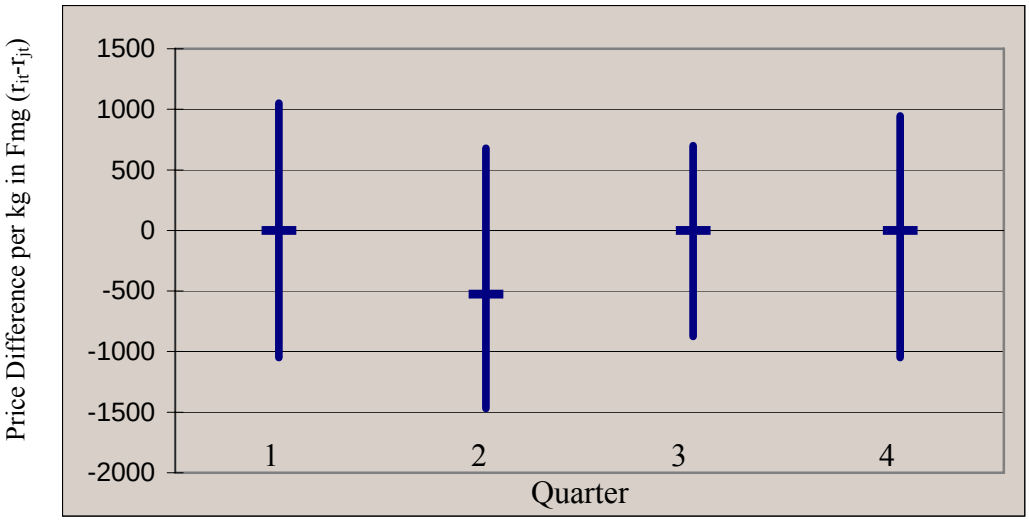

Figure 3. Median and span of price differences at the regional level
(Spans are trimmed at the 5th and 95th percentiles)

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