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NOTE

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The economic potential for area-yield crop insurance: An application to maize in Ghana

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Abstract

Rainfall index insurance can enable farm households to manage production risk, but demand in developing countries remains low at market prices, in part because the insurance trigger may not correlate well with individual farm losses. Area-yield crop insurance, which links payouts to average yield in a geographic zone, attempts to increase demand by more accurately targeting insurance payouts to production shortfalls. However, shifting from an exogenous weather-based to an endogenous yield-based index introduces concerns of asymmetric information, which can lead to market failures that constrain supply from providers. These features are inversely related: larger insurance zones inhibit index manipulation, but average yield is less informative about any individual plot. We quantify this tradeoff for maize in Ghana using a spatial yield model calibrated to match observed production. Insurers must demarcate zones of no more than 5000 farmers for area-yield insurance to outperform weather insurance. The framework presented in this paper allows assessment of the relationship between index performance and asymmetric information in new crop insurance products.

KEYWORDS
agricultural insurance, area-yield insurance, basis risk, Ghana, maize

JEL CLASSIFICATION
G22, O13, Q14

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1 | INTRODUCTION

Risk remains a salient barrier to agricultural investment and rural development. Crop insurance can insulate farm households from production risk, but directly insuring individual on-farm yield may be hampered by asymmetric information (Gunnsteinsson, 2020). To limit market failures due to adverse selection and moral hazard, insurers in developing economies often base payouts on readily observable exogenous factors such as low rainfall.

Weather-based index insurance has proven to promote investment and prevent decapitalisation in subsidised field trials (see Cole & Xiong, 2017, for a review), yet demand at market prices remains low in developing countries (e.g. Cole et al., 2017). One prominent factor diminishing its appeal is the presence of basis risk, which arises in cases of mismatch between insurance payouts and individual farm losses. Downside basis risk, when insurance fails to trigger despite revenue shortfalls, is especially costly to those near subsistence for whom unrecovered premia constitute a substantial burden in times of loss (Clarke, 2016).

Area-yield index insurance, in which payouts are based on average yield in a geographic zone, can raise demand by more comprehensively encompassing on-farm crop loss. Field trials show promise on very small zones (e.g. Casaburi & Willis, 2018; Stoeffler et al., 2021), but linking payments to an endogenously determined outcome reintroduces asymmetric information that can constrain suppliers' willingness to issue such policies. To sustain an area-yield insurance market, insured zones must be sufficiently large that providers are protected from coordinated responses by policyholders within the zone.

In this paper, we assess whether area-yield index insurance can lower basis risk for policyholders while still mitigating asymmetric information for providers. Our analysis complements work by Stigler and Lobell (2024), Gallenstein and Dougherty (2024), and Tsiboe et al. (2023) in the US context, which quantifies the basis risk and associated insurance value to policyholders of switching from exogenous weather-based to endogenous yield- and price-based indices within a fixed insurance pool. We introduce a framework to weigh such improvements in index performance, which can raise demand from policyholders, against supply-side concerns of asymmetric information and index manipulation in small insurance zones that may hinder the financial viability of products offered by insurance providers.

The underlying insight is that as an index zone grows, and, therefore, the capacity to sustain internal coordination shrinks, basis risk increases. We identify the largest possible area-yield index zone that improves basis risk over rainfall insurance by calibrating a spatial model using data on maize in Ghana. Results indicate area-yield index insurance can only outperform rainfall index insurance, leading to greater consumer demand, if insurers operate zones of no more than 8 kilotonnes (kt), encompassing roughly 5000 farmers on average. We encourage this style of economic analysis when designing crop insurance contracts.

2 | THEORY

Plot-level productivity can be described in relation to an insurance contract by insured and uninsured components. Formally, let yield Y_{it} on plot i in year t be

$$Y_{it} = \gamma_i + \beta T_{it} + \varepsilon_{it} \tag{1}$$

where γ_i is average (anticipated) yield, T_{it} is the index realisation that determines payouts, β scales the index to output, and ε_{it} is uninsured productivity variation.

We define the performance of an insurance index as the correlation between realisation of the index variable T_{it} and on-farm yield Y_{it}. Insurance value to policyholders, and, therefore, market demand, increases with index performance. The remaining uninsured variation constitutes basis risk, formally quantified as the ratio of uninsured to total production variance:

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$$\mathrm{BR} = \frac{\mathrm{Var}_t\, \varepsilon_{it}}{\mathrm{Var}_t\, Y_{it}} \tag{2}$$

The maximally performing index perfectly reflects on-farm yield as $\beta T_{it} = Y_{it} - \gamma_i$ with zero residual variance in ε_{it}. This would enable insurance to directly cover individual on-farm losses, but may generate market failures if asymmetric information allows farmers to adjust their yield or coverage in response to the contract. Such strategic behaviour is mitigated in the U.S. market, where individual indemnity insurance is prevalent, through precise input monitoring and history-dependence in long-term contracts (Mieno et al., 2018, see). However, in developing economies with lower institutional capacity and weaker contracting environments, insurance payouts are more commonly indexed to external outcomes.

Traditional index insurance contractually defines T_{it} using exogenous productivity-related factors such as rainfall or temperature. Such contracts avoid information asymmetry because, conditional on climate, weather is a publicly observable random shock outside farmers' control. In principle, insurance could be indexed to precise plot-level weather conditions with the appropriate measurement technology. However, even this level of granularity leaves substantial uninsured risk from non-weather-related loss.

Area-yield insurance, which defines T_{it} as average productivity within a geographic zone, offers an attractive alternative to improve index performance by better reflecting plot-level outcomes. Expanding the index zone to include many plots mitigates concerns of information asymmetry as individuals have less influence over the index outcome, but does so at the cost of increasing basis risk as the zone average becomes less informative about each plot in the zone.

In this study, we quantify how the index performance of area-yield insurance degrades with index zone size. We then identify how small a zone an insurer must demarcate to improve over weather insurance. We analyse maize in Ghana, and our methods readily extend to other crops, regions, and types of indices.

3 | DATA

The ideal data to estimate both average production, as well as year-to-year variability within an insurance zone, would be a plot-level panel. Unfortunately, long time series and high granularity are rare at large scale in developing countries.[1] We instead benchmark local production to the Global Agro-Ecological Zones (GAEZ) database, which combines time-invariant soil, terrain, and climate conditions to apportion national production across geographic units (FAO & IIASA, 2023). This cross-sectional apportionment is treated as anticipated productivity, defined by γ_i in (1). We then use data on annual output and area harvested reported by the Ghana Ministry of Food and Agriculture (MOFA) from 2006 to 2011 for the country's then 138 districts to compute yearly deviations. Full details are given in Appendix S1.

3.1 | Basis risk

The index performance of area-yield insurance is the correspondence between plot and index zone productivity shocks. To quantify this correspondence, we decompose

[1]Advances in remote sensing offer future promise, but historical records are unavailable and correspondence with ground truth remains low (e.g. Jin et al., 2017).

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district-level production variability into shocks at the 9 km × 9 km tract level delineated in GAEZ data by modelling the data-generating process for tract-level yield as a spatially autocorrelated random draw. Covariance parameters in the model are calibrated to match measured district-level deviations reported by MOFA from the GAEZ benchmark, with details provided in Appendix S2. We calculate area-yield index performance and basis risk using the correlation between tract-level productivity shocks and index zone aggregate shocks implied by the calibrated model.

3.2 | Market size

The scope for index manipulation and other forms of moral hazard depend on the size of the pool used to compute the index. We calculate production volume in an area-yield index zone using the GAEZ's measure of anticipated yield. For each index zone size, we define volume as the average of this value across all possible zones of that size.

4 | RESULTS

Model calibration indicates spatial correlation in productivity over the range of three GAEZ tracts. Beyond 27 km, common components of maize yield shocks are indistinguishable from background noise. We report the implications for area-yield insurance in Figure 1.

The lighter curve represents basis risk averaged across all tracts in a fixed zone, reflecting how zones are traditionally demarcated. Basis risk is lowest at the centre and increases toward the edges, where adjacent tracts with similar productivity shocks may fall outside the index zone. The darker curve illustrates the potential to improve index performance by designating tract-specific index zones centred around each insured tract. Such precision is becoming increasingly accessible as remote sensing enables measurement at finer spatial resolutions.

Over small areas, basis risk grows faster with size in the fixed-zone contract because it adds more peripheral tracts where the index performs poorly. The gap is most pronounced in the 0.5–25 kt range and subsequently narrows as zones grow too large to be informative. By 50 kt, corresponding to 80 km × 80 km zones, the signal value of area-yield is almost completely degraded.

For comparison, the horizontal line represents basis risk in weather index insurance. This benchmark is calibrated from analyses of national maize production in West Africa (Lobell & Burke, 2008) and plot-level maize production in Kenya (Stigler & Lobell, 2024). Both studies report a correlation between rainfall and output of around 0.33, indicating a basis risk of 0.67. Index performance does not vary with volume because the exogenous index already minimises asymmetric information, so there is no benefit to coarsening the resolution of the index as the market grows.

For area-yield insurance to improve on the basis risk of weather insurance, index zones must be at most 34 km × 34 km—representing production of 8 kt or less. This volume corresponds to roughly 5000 maize-producing households per insurance zone (from Ghana Statistical Services, 2020). Allowing tract-specific area-yield indices relaxes this constraint to 40 km × 40 km zones—containing 7000 farm households producing 11.3 kt of maize. Internal collusion to manipulate an index would be difficult to sustain at these production scales, so we speculate there is scope for area-yield to improve performance in index insurance in this setting without triggering market failure.

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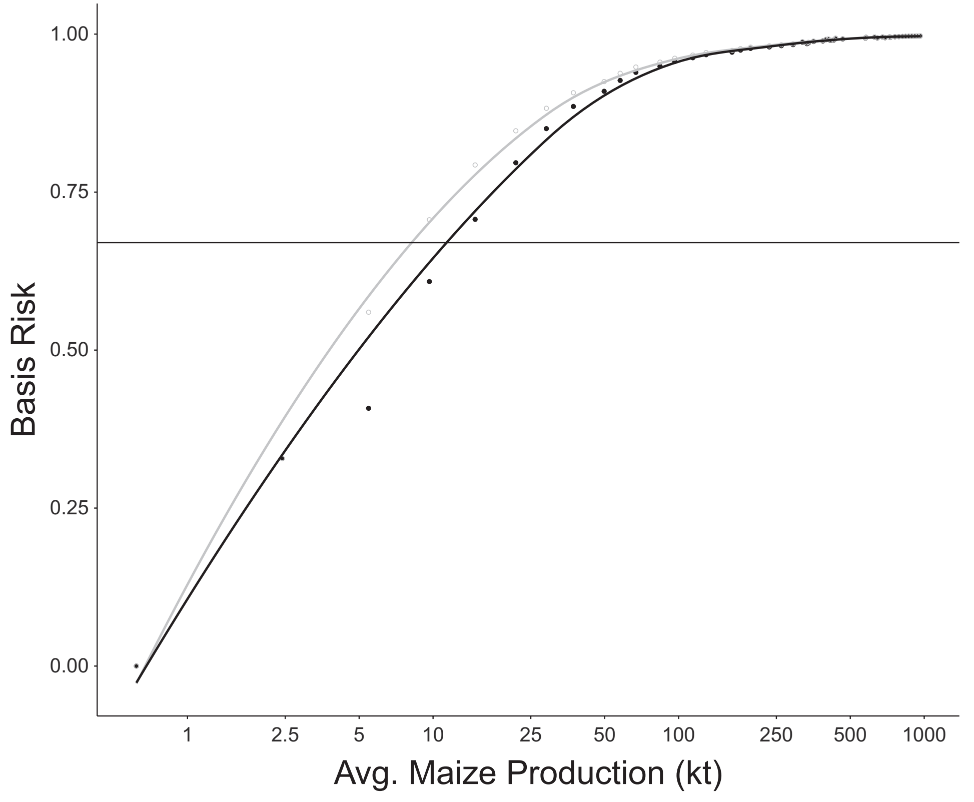

FIGURE 1 Basis risk vs. market size in area-yield insurance. *Note*: The vertical axis measures basis risk defined by (2); the horizontal axis denotes the average production volume in kilotonnes (kt). Grey circles and fitted curves represent average index performance across all tracts in insurance zone. Black dots and fitted curves represent index performance in the central tract. The horizontal line shows basis risk of weather insurance.

5 | DISCUSSION

We introduce a general framework to characterise the tension in area-yield index insurance between basis risk, which can lower demand, and asymmetric information, which can constrain supply. This tension, inherent to any agricultural index insurance that aggregates endogenous outcomes, arises because index performance is improved through compactness in insurance pools, while mitigating asymmetric information requires expanding the size of the pool used to compute the index. We calibrate a production model to quantify the tradeoff between these two features for Ghanaian maize.

For area-yield insurance, this tradeoff depends crucially on spatial correlation in productivity because lower variance allows for larger insurance zones to achieve the same level of basis risk. We implement a tractable calibration approach to infer higher-resolution spatial variation from district-level production data. Our methodology limits analysis to correlational measures of index performance. More complex utility-based assessment (e.g. Conradt et al., 2015) is sensitive to distributional assumptions about the tails of data-generating process, and would be possible to incorporate into our framework with richer spacio-temporal yield data.

The calibrated model indicates maize insurers in Ghana must designate insurance zones encompassing no more than 5000–7000 farmers for an area-yield index to outperform weather index insurance. This scale is likely too large to sustain internal coordination to manipulate yield realisations, but the capacity for collusion and extent of moral hazard are ultimately

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context-specific empirical questions beyond the scope of this paper to quantify. In the end, determining an acceptable level of exposure to information asymmetry remains at the discretion of insurance providers.

This paper analyses area-yield insurance on 9 km × 9 km tracts, matching the spatial resolution of rainfall insurance offered by the Ghana Agricultural Insurance Pool. Both weather and crop productivity are observable through remote sensing at this level of resolution, but Stigler and Lobell (2024) estimate residual plot-level yield variation of around 0.5 within tracts of this size. Therefore, smaller index zones would be needed to compete with more finely targeted plot-level weather insurance.[2] On the contrary, many existing weather-based products aggregate larger regional patterns (e.g. Awondo, 2019) and likely perform far worse, leaving substantial scope for improving index performance.

Alternate approaches to address basis risk with exogenous indices expand the scope of named hazards to include, for example, pests or fire. Our framework readily accommodates comparisons with such contract structures. We encourage this type of analysis to evaluate potential supply-side market constraints when introducing new forms of agricultural insurance based on endogenous outcomes.

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CONFLICT OF INTEREST STATEMENT

No institution had the right to review results before publication.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Ghana Open Data Initiative at https://data.gov.gh/search/type/dataset, reference number 0186db50-af20-4385-97be-91c013659069.

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[2]It is worth noting that differences in the cost of measuring plot-level weather and yield outcomes add an additional dimension of complication to comparisons of market viability between different types of high-resolution insurance products.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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