Understanding the Dynamics of Crop Insurance Markets through an Exploratory Model

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Mitigating agrarian distress remains a global policy priority, with food security and community resilience as cornerstone of Sustainable Development Goals. Crop insurance has long been viewed as a mechanism to safeguard farmers against production risks. However, despite decades of subsidies and policy support, participation rates remain limited across major agrarian economies. Flagship schemes in India or the federally subsidised programme in the United States continue to operate as 'incomplete markets', characterised by systemic risks, information asymmetry, and the difficulty to diversify losses across space or time. Literature has highlighted consequent issues related to adverse selection, moral hazard, and basis risk, while the problem of correlated yields undermines the fundamental principle of risk pooling. Government subsidies, though significant, have not resolved these structural challenges, that deserve a deeper look and could lead to a self-sustaining, market-based solution.

Recent studies (Consiglio & Giovanni, 2008; Carter et al., 2017; Sethanand et al., 2023) have increasingly emphasised the role of technological innovations, particularly remote sensing and advanced data processing, to improve crop monitoring, yield forecasting, and claim settlement. While index insurance reduces transaction costs, it introduces basis risk that discourages farmers. Consequently, researchers and policymakers are now exploring whether data-driven and technology-assisted solutions can meaningfully address the underlying market failures. Against this backdrop, our work examines the systemic roots of incompleteness in crop insurance markets. It evaluates whether ongoing innovations, particularly satellite-based monitoring and index insurance, can facilitate a viable market mechanism or whether subsidies will remain an enduring feature of agricultural risk management.

The purpose of the model is to explore the dynamics that drive market failure in crop insurance and to assess the conditions under which welfare interventions become necessary. The scope encompasses the entire insurance cycle from premium quotation to claims settlement while accounting for interactions between insurers, farmers, and government agencies providing subsidies. To represent uncontrollable factors such as weather and the varying perceptions about risks by different stakeholders, stochastic noise was incorporated into the framework.

The model is structured around annual crop cycles, with three principal feedback loops. The first, a reinforcing loop (R1), captures the interdependence between premiums (price) and coverage (demand) as follows: higher premiums reduce demand, which raises the fixed cost burden per policy, further escalating premiums and potentially driving coverage towards zero. Conversely, low (heavily subsidised) premiums can encourage high coverage, yielding equilibrium when subsidies absorb much of the premium loading and administrative costs. A second loop (B1) represents the buyer satisfaction dynamic, whereby errors in claims settlement lead to customer dissatisfaction and a multiplier effect on suppressing future demand, thereby limiting market penetration. The third loop (R2) models the influence of insurers' historical claims experience on premium setting, highlighting

how high realised losses, whether due to poor data quality or fraud feed back into risk assessments and premium calculations.

Extensive simulations using plausible parameter ranges derived from literature and informed judgement reproduced behaviours consistent with real-world crop insurance markets. Results suggest that the price elasticity loop (R1) dominates system dynamics, driving instability unless subsidies are substantial. The model, developed as an exploratory framework following Richardson (2024), offers a structured basis for understanding the persistence of market failure in crop insurance and provides a platform for testing policy interventions under alternative initial conditions.

Simulation runs over five decades for key variables, including geographical variability, data quality, coverage, subsidies, and customer satisfaction, exhibit behaviours consistent with both market failure and conditional stability. In high-risk geographies, claim events often trigger a reinforcing cycle of escalating premiums and shrinking coverage, resulting in insurers exiting the geographies. Data quality plays a role in customer dissatisfaction, but does not materially alter overall dynamics. Index insurance fails to mitigate instability, while premium subsidies prove effective only if sufficiently large in the early years to stabilise risk estimates and premiums; modest subsidies (e.g., 10% of sum assured) remain inadequate in high-risk contexts.

This study presents an exploratory system dynamics model to examine the market failures in crop insurance. By simulating the interactions between farmers, insurers, governments, and exogenous risks, the model demonstrates how reinforcing feedbacks particularly the premium–coverage loop, drives instability unless substantial subsidies or policy interventions are introduced. While parameter calibration remains approximate, sensitivity analyses suggest that the broad insights are robust, highlighting the critical role of elasticity, loading, and fixed costs in shaping outcomes. The framework underscores the value of dynamic modelling in policy discourse. Future work should refine parameter estimation, incorporate strategic behaviour of insurers, and engage stakeholders in participatory model-building to strengthen policy relevance.

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References

Banson, K. E., Nguyen, N. C., and Bosch, O. J. (2018). A systems thinking approach to the structure, conduct and performance of the agricultural sector in Ghana. *Systems Research and Behavioral Science*, 35(1), 39-57.

Barnett, B. J. (2004). Agricultural index insurance products: strengths and limitations. In *Agricultural Outlook Forum* 2004 (No. 32971). United States Department of Agriculture, Agricultural Outlook Forum.

Bera, S. (2019). Crop insurance flaws fuel farm distress. *Mint New Delhi*, 13(278) pp 8. Retrieved March 30th, 2021. https://www.livemint.com/news/world/crop-insurance-flaws- fuel-farm-distress-11574185759756.html

Burfisher, M. E. (2021). *Introduction to Computable General Equilibrium Models*. Cambridge University Press.

Burgaz, (2010). The Spanish Agricultural Insurance Scheme: National Experiences and Recommendations Looking at the cap post-2013. in *Directorate General for Internal Policies Policy Department B: Structural and Cohesion Policies Agriculture and Rural Development* [report]. https://www.europarl.europa.eu/RegData/etudes/note/join/2010/438593/IPOL-AGRI_NT(2010)438593_EN.pdf

Carter, M. R., Cheng, L., and Sarris, A. (2016). Where and how index insurance can boost the adoption of improved agricultural technologies. *Journal of Development Economics*, 118, 59-71.

Carter, M., de Janvry, A., Sadoulet, E., &and Sarris, A. (2017). Index insurance for developing country agriculture: a reassessment. *Annual Review of Resource Economics*, 9(1), 421-438.

Consiglio, A., and De Giovanni, D. (2008). Evaluation of insurance products with guarantee in incomplete markets. Insurance: Mathematics and Economics, 42(1), 332-342.

Enjolras, G., and Sentis, P. (2011). Crop insurance policies and purchases in France. *Agricultural Economics*, 42(4), 475-486.

Ghosh, R. K., Gupta, S., Singh, V., and Ward, P. S. (2021). Demand for crop insurance in developing countries: New evidence from India. *Journal of Agricultural Economics*, 72(1), 293-320.

Ginsburgh, V., and Keyzer, M. (2002). *The Structure of Applied General Equilibrium Models*. MIT Press.

Goodwin, B. K. (2001). Problems with market insurance in agriculture. *American Journal of Agricultural Economics*, 83(3), 643-649.

Goodwin, B. K., and Smith, V. H. (2013). What harm is done by subsidizing crop insurance?. *American Journal of Agricultural Economics*, 95(2), 489-497.

Gulati, A., Terway, P., and Hussain, S. (2018). *Crop insurance in India: Key issues and way forward* (No. 352). Working paper. Indian Council for Research on International Economic Relations.

Hieronymi, A. (2013). Understanding systems science: A visual and integrative approach. *Systems Research and Behavioral Science*, 30(5), 580-595.

Homer, J., and Oliva, R. (2001). Maps and models in system dynamics: a response to Coyle. *System Dynamics Review*, 17(4), 347-355.

Innes, R. (2003). Crop insurance in a political economy: An alternative perspective on agricultural policy. *American Journal of Agricultural Economics*, 85(2), 318-335.

Kimura, S., Wehrhahn, R., Lin, W., and Zhang, L. (2022). *Developing a Sustainable Agricultural Insurance System in the People's Republic of China*. Asian Development Bank. https://dx.doi.org/10.22617/BRF220530-2

Kölle, W., A. Martínez Salgueiro, M. Buchholz, and O. Musshoff. (2021). Can satellite-based weather index insurance improve the hedging of yield risk of perennial non-irrigated olive trees in Spain? *Australian Journal of Agricultural and Resource Economics*, 65(1), 66-93.

Kramer, B., Hazell, P., Alderman, H., Ceballos, F., Kumar, N., and Timu, A. G. (2022). Is agricultural insurance fulfilling its promise for the developing world? A review of recent evidence. *Annual Review of Resource Economics*, 14, 291-311.

Liao, C., Ross, H., Jones, N., and Palaniappan, G. (2024). System lacks systems thinking: Top-down organization and actor agency in China's agricultural extension system. *Systems Research and Behavioral Science*, 41(1), 82-99.

Makki, S. S., and Somwaru, A. (2001). Evidence of adverse selection in crop insurance markets. *Journal of Risk and Insurance*, 685-708.

Miranda, M. J., and Glauber, J. W. (1997). Systemic risk, reinsurance, and the failure of crop insurance markets. *American Journal of Agricultural Economics*, 79(1), 206-215.

Mukherjee, S., and Pal, P. (2017). Impediments to the spread of crop insurance in India. *Economic and Political Weekly*, 16-19.

Murthy, C. S., Poddar, M. K., Choudhary, K. K., Srikanth, P., Pandey, V., Ramasubramanian, S., and Kumar, G. S. (2022b). Remote sensing based crop insurance for jute (Corchorus olitorius) crop in India. *Remote Sensing Applications: Society and Environment*, 26, 100717. https://doi.org/10.1016/j.rsase.2022.100717

Paulson, N. D., Babcock, B., and Coppess, J. (2014). The potential for crop insurance reform. *Agricultural Finance Review*, 74(4), 464-476.

PMFBY. (2024, June 30th). *Administrative Dashboard*. Pradhan Mantri Fasal Bima Yojana. https://pmfby.gov.in/adminStatistics/dashboard

Richardson, G. P. (2024). Building confidence in exploratory models. *System Dynamics Review*. https://onlinelibrary.wiley.com/doi/10.1002/sdr.1769

Roth, S. (2018). Market therapy? On intervention in the consociation with non-members. Systems *Research and Behavioral Science*, 35(1), 127-138.

Sethanand, K., Chaiyawat, T., and Gowanit, C. (2023). Systematic process for crop insurance development: area-yield rice insurance with machine learning technology implementation in Thailand. *Agricultural Finance Review*, 83(3), 416-436.

Sterman, J. D. (2023*). Business dynamics: Systems thinking and modeling for a complex world*. Chennai: McGraw-Hill Education (India) Private Limited. (Original work published 2000).

Stiglitz, J. E., and Rosengard, J. K. (2015). *Economics of the public sector (4e)*. WW Norton & Company.

The World Bank (n.d.). *Brazil - Agricultural Market Insurance Development : Policy Note*. World Bank. https://documents1.worldbank.org/curated/en/268351520343354377/pdf/123948-WP-6-3-2018-8-39-22-AriasetalAgriculturalgrowthinBrazil.pdf

USDA. (2024). *Standard Reinsurance Agreement*. United States Department of Agriculture. https://www.rma.usda.gov/-/media/RMA/Regulations/Appendix-2025/25sra.ashx

Valentinov, V., and Chatalova, L. (2014). Transaction costs, social costs and open systems: Some common threads. *Systems Research and Behavioral Science*, 31(2), 316-326.

Valentinov, V., and Chatalova, L. (2016). Institutional economics and social dilemmas: a systems theory perspective. *Systems Research and Behavioral Science*, 33(1), 138-149.

Walters, C. G., Shumway, C. R., Chouinard, H. H., and Wandschneider, P. R. (2015). Asymmetric information and profit taking in crop insurance. *Applied Economic Perspectives and Policy*, 37(1), 107-129.

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