

Fostering MSME sustainability through sharia-based sovereign-backed equity: An exploratory ABM-SDE simulation of proposed LPI-UMKM

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Abstract

The present study explores the impact of debt-based microfinance on the long-term socio-economic sustainability of Micro, Small, and Medium Enterprises (MSMEs) during crises. Conventional state interventions frequently result in the depletion of national budgets without building systemic resilience. The present paper propose *Lembaga Penjamin Investasi* (LPI) UMKM, sovereign-backed mechanism designed to transition MSME financing from debt-dependency to sustainable equity-based participation. Utilizing a hybrid Agent-Based Modeling and Stochastic Differential Equation (ABM-SDE) framework, we simulate the explore effectiveness of this framework under various stress conditions. By ensuring continuous capital circulation through sovereign-backed equity, this mechanism is in alignment with UN's Sustainable Development Goals (SDGs) and creates resilient financial infrastructure that prevents permanent loss of productive capacity in the micro-enterprise sector. Interpreting simulation outputs through proposed three-pillar Sustainability Index (SI-LPI), the study demonstrates a demonstrable improvement over debt-based systems, positive fiscal sustainability trajectories, and significant crisis absorption. It also demonstrates the mechanism's theoretical contributions to SDG 1, SDG 8, SDG 9, SDG 10, SDG 12, and SDG 17. While Green Procurement Score is additionally identified as a structurally embeddable indicator for future circular economy and green finance integration, the study also anticipated incorporate moral hazard, capital diversion, bank risk inflation, and fiscal leakage multipliers.

Keywords: MSME financing, macroeconomic framework, equity, digital locked-loops, green finance, social sustainability, SDG metrics

1. Introduction

The global microfinance sector, particularly within the paradigm of Islamic banking, faces a persistent structural paradox. The philosophical foundation of Islamic finance advocates for equity-based, profit-and-loss sharing (PLS) investments, primarily in the form of *Mudharabah* and *Musyarakah*. However, empirical reality demonstrates a massive, systemic over-reliance on debt-like, mark-up instruments such as *Murabahah* [1]. It is widely criticized as "debt-mimicry", highlighting a notable tension between theoretical ideals and operational survival [2]. Under the strict capital adequacy requirements of Basel III, uncollateralized passive investments have the potential to engender a grave threat to bank liquidity, particularly in the context of exogenous macroeconomic shocks [1],[3].

MSMEs typically operate in highly volatile environments, frequently lack hard collateral, and exhibit high non-performing financing (NPF) rates, particularly during

exogenous economic shocks such as the COVID-19 pandemic [4],[5]. Consequently, financial institutions tend to adopt fixed-income models as a means to shield their balance sheets and maintain capital adequacy as stipulated by the Basel III frameworks [3]. With the absence of hard collateral, passive investments in the MSME sector expose banks to unquantifiable asymmetric information and moral hazard risks [6]. To bridge this critical gap, public credit guarantee schemes (PCGS) have been implemented on a global scale. However, traditional models frequently exacerbate moral hazard, thereby encouraging excessive bank risk-taking without fundamentally improving the survival rate of the underlying MSMEs [7], [8]. This paper introduces a departure from traditional PCGS: Proposed LPI-UMKM (*Lembaga Pengelola Investasi Usaha Mikro-Kecil dan Menengah*) framework, conceptualized as a specialized sovereign wealth mechanism [9].

LPI-UMKM is proposed as a reverse LPS (Indonesian Save Insurance Corporation) to mitigate the risk of banks failures due to the failures of MSMEs. This is in the opposite to LPS that mitigates the risk of savers to the Banks failures [10]. However, the maturity of framework and effectiveness needs further elaboration and scientific based simulation tests prior to

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its partial deployment to real implementation for empiric effectivity and reproducibility [11]. The present study utilizes Hybrid ABM-SDE framework coupled with Markov State Transitions to computationally stress-test the LPI-UMKM against severe volatility. The final goal of this study is to formulate a candidate framework that might enhance the sustainability of MSMEs.

MSMEs sustainability extends beyond mere financial survival, encompassing social, environmental, and economic dimensions that are central to UN Sustainable Development Goals (SDGs). This present study also proposes a three-pillar Sustainability Index for LPI-UMKM (SI-LPI), the indicators of which are partially operationalizable within the present simulation framework and fully specifiable for future empirical measurement.

From social sustainability perspective, the MSME Survival Rate Differential (SRD) is defined as the relative improvement in agent survival under LPI-UMKM compared to conventional financing baselines. This serves as a proxy for aggregate employment preservation. Indonesian MSMEs collectively account for approximately 97% of national employment and 61% of GDP [12]. Consequently, a one percentage point of survival rate improvement represents a measurable contribution to SDG 8 (Decent Work and Economic Growth) and SDG 1 (No Poverty). Additionally, the Financial Formalization Rate (FFR) as captured within the ABM, i.e. the proportion of agents transitioning from the micro-tax to the

corporate tax regime, quantifies the pace of financial inclusion and institutional integration, directly relevant to SDG 10 (Reduced Inequalities) [12].

From an environmental sustainability perspective, the equity-based Locked-Loop architecture established the structural preconditions for green finance integration that debt instruments cannot. Unlike fixed-repayment models that compel MSMEs to subordinate ecological considerations to cash flow obligations, equity partnerships have been demonstrated to allow the sovereign fund to mandate a Green Procurement Score (GPS) which is defined as the proportion of Locked-Loop supply-chain transactions routed to environmentally certified or sustainably sourced suppliers as a qualifying criterion for ongoing capital injections. While the GPS is not empirically calibrated within the present simulation, its embeddability within the existing supply-chain whitelisting mechanism is a technically immediate pathway for SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) compliance.

From an economic sustainability perspective, the Fiscal Sustainability Index (FSI) (the ratio of the sovereign fund's terminal value to its initial capitalization) provides a measurable indicator of whether the mechanism is self-sustaining or permanently reliant on budget transfers, which is directly relevant to SDG 17 (Partnerships for the Goals). The three pillars are detailed in Section 2.1.4, and their simulation-derived estimates are reported in Section 3 (See Fig. 1).

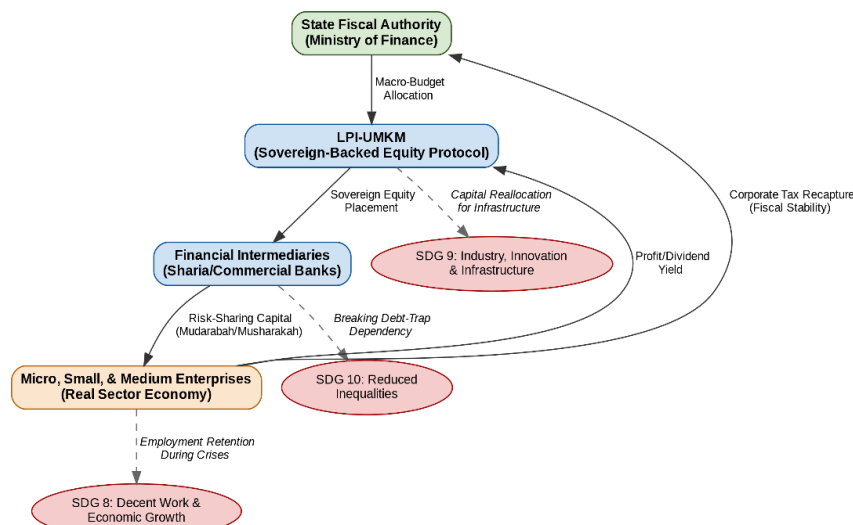


Fig. 1. Diagram of Proposed LPI-UMKM framework and SDGs related contributions

2. Materials and Methods

2.1. Proposed LPI-UMKM conceptual framework

2.1.1. Equity-based partnership with digitalization

Bank precisely purchases operational assets for the MSME, thereby acquiring an ownership stake and generating non-usury profit based strictly on business performance. Equity-based financing inherently transfers business risk to the Investor Bank. This risk can be mitigated by several restrictions:

- By restricting capital usage strictly to stable assets such as

properties or capital on Locked-Loop digital wallets. This approach ensures the transparent routing of investment funds to verified suppliers using bank-controlled digital payment methods (such as QRIS in Indonesia). It is supposed to neutralize the severe inaccurate information and operational fraud that have traditionally deterred risk-averse banks from PLS arrangements.

- To ensure inclusion and address Digital Marginalization of rural actors, the proposed framework integrates Village Government-funded Public Cooperatives (for example *Koperasi Merah Putih* in Indonesia) as secondary layer. These entities facilitate necessary digital onboarding,

physical verification, and function as localized nodes for transaction routing, thus ensuring that no market actor is excluded.

- In fail-safe exists: MSME Investment Guaranteed Corporation (LPI-UMKM). The mechanism that functions as a reverse deposit insurance mechanism provides a pre-defined limit of investment recovery for the bank.

In the proposed design, the mechanism is funded by reallocating existing KUR subsidy allocations, rather than through new borrowing. This is intended to limit direct additions to the national debt stock. However, it should be noted that sovereign guarantee funds can create contingent fiscal liabilities that credit rating agencies and international financial institutions (e.g., IMF Fiscal Monitor frameworks) include in broader measures of fiscal risk exposure, regardless of their on-balance-sheet treatment [13]. The precise fiscal classification of LPI-UMKM would require formal determination by the Ministry of Finance under applicable Indonesian public finance law.

2.1.2. Profit and risk sharing

The transition from debt-burden to an equity-sharing reduces the insolvency of systemic inequality harm and promote the equitable wealth circulation. This framework is also supposed to reduce or partially solve the taxation dilemma. State taxes levied on small businesses have been viewed as a way for the state to demand fixed profits without bearing any capital burden or business risk [14]. Within this framework, the national budget directly injects subsidies into LPI-UMKM to secure the bank's position against the risk of MSMEs liquidation. It directly includes the state entering as a Risk-Sharing Partner. Based on the sharia and equity-based system, reward is justified by the assumption of risk, the taxes automatically withheld collectively from MSMEs to sovereign asset insurance provided by the state. The system under discussion here is characterized by its three-dimensional structure, which encompasses usury-free savings, collateral-free capitalization (equity), and tax rate that is not framed as a contractual Sharia-compliant dividend index. Rather, it is conceived of as collective fiscal recapture mechanism for the sustainability of MSMEs finance through LPI-UMKM. The state's yield is justified through public finance frameworks where sovereign equity injections generate non-debt tax revenues from stabilized micro-enterprise growth, thereby replacing direct debt service with macro-fiscal sustainability.

2.1.3. Sustainability elements of proposed LPI-UMKM

The implementation of LPI-UMKM offers benefits that extend beyond immediate financial relief; it has the potential to foster long-term socio-economic sustainability by mitigating 'social entropy' typically caused by debt-driven enterprise failures during crises. The mechanism ensures continuous capital circulation through the use of sovereign-backed equity, thereby aligning with the UN's Sustainable Development Goals (SDGs), particularly Goal 8 (Decent Work and Economic Growth) and Goal 9 (Industry, Innovation, and

Infrastructure). The establishment of a resilient financial infrastructure is pivotal in preventing the permanent loss of productive capacity in the micro-enterprise sector.

2.1.4. Operationalizing the SI-LPI Sustainability Metrics

To provide a reproducible measurement foundation for the multi-dimensional sustainability claims of the LPI-UMKM framework, Table 1 presents the proposed Sustainability Index for LPI-UMKM (SI-LPI). This index comprises six indicators across three pillars. Indicators marked as "simulation-derivable" are reported quantitatively in Section 3; those marked "proposed" are conceptually operationalized here and recommended for future empirical calibration.

Table 1. Proposed SI-LPI sustainability indicators, measurement basis, and SDG alignment

Pillar & (SDG Alignment)	Indicator	Definition	Measurement Basis
Social (SDG 1, SDG 8)	MSME Survival Rate Differential (SRD)	(LPI-UMKM survival % – conventional baseline %) / conventional baseline %	ABM simulation output
Social (SDG 9, SDG 10)	Financial Formalization Rate (FFR) [15] [16]	% of ABM agents transitioning from micro-tax (0.5%) to corporate tax (22%) regime [17]	ABM agent state transitions
Economic (SDG 17)	Fiscal Sustainability Index (FSI)	Fund terminal value (Year 10) / Initial fund capitalization	SDE simulation output
Economic (SDG 9)	Crisis Absorption Efficiency (CAE)	1 – (S3 defaults with LPI-UMKM / S3 defaults in unbacked scenario)	Markov state transitions
Environment (SDG 12, SDG 13)	Green Procurement Score (GPS)	% of Locked-Loop transactions routed to eco-certified suppliers	Supply-chain whitelist data (proposed)
Environment (SDG 13)	Carbon Footprint Reduction Proxy (CFRP)	Estimated CO ₂ reduction from digital versus cash-based supply-chain transactions	Lifecycle analysis (proposed)

The social pillar addresses a structural gap in conventional MSME financing: since survival is directly linked to employment, any mechanism that significantly raises MSME survival rates under crisis conditions is, in effect, a tool for preserving employment. The SRD operationalizes this link without requiring household-level survey data, making it computationally tractable within the present simulation while remaining interpretively grounded in established labor economics [18].

The economic pillar recognizes that sustainability of the mechanism itself is not solely dependent on the MSMEs it supports, but also constitutes a first-order condition. A sovereign fund that exhausts its capital within the simulation horizon cannot be considered a sustainable policy instrument regardless of short-term survival rate improvements. The FSI

and CAE together are capable of capturing both solvency and stabilization effectiveness.

Of the three pillars, the environmental pillar is the most prospective. Current literature on green Islamic finance demonstrates an increasing tendency to use equity-based instruments, particularly *musharakah* structures, for the integration of environmental covenants. This is due to the contractual capacity of profit-sharing partners to require environmental performance as a condition of ongoing capital participation [19]. The GPS operationalizes this principle within the LPI-UMKM's whitelisting architecture, with a GPS threshold of 30–50% is estimated as technically feasible without imposing prohibitive compliance costs on MSME participants at the initial rollout phase, consistent with tiered green finance adoption frameworks in emerging markets [19].

2.1.5. Formalization pathway and industrialization related to SDGs goal 9 (industry, innovation, and infrastructure)

The current withholding tax for MSMEs serves merely as a formalization entry point. It is inevitable that these enterprises will be incorporated into the standard corporate tax regime. By automating this transition, the framework establishes Tax Buoyancy, defined as the system's ability to increase revenue as the economy grows. Achieving the 15% tax-to-GDP ratio target without overburdening the existing formal sector is dependent on this [20]. The provision of technical gatekeepers to banks, facilitated via the bank-controlled QRIS, creates a verified financial history. This dataset serves as a high-velocity launchpad for the BEI Acceleration Board. The increase in the sheer volume of listed companies on the Bursa Efek Indonesia (BEI) has had a radical effect on the democratization of the capital market, acting as a gravitational well, attracting massive Foreign Direct Investment (FDI) inflows. The strategic management, extreme discipline, and innovation which are prerequisites for surviving an IPO significantly enhance the global competitiveness of local brands [21].

The Republic of Indonesia is in urgent need of more export-oriented MSMEs. Currently, MSME contribution to the non-oil and gas sector is a mere 19%. The provision of the vital "Locked-Loop" equity capital is essential for facilitating high-quality, export-grade production, thereby enabling firms to enter global supply chains, inherently driving a Trade Surplus. In theoretical terms, increased export-oriented MSME activity would raise foreign currency inflows, which may contribute to exchange rate stability. However, this macroeconomic transmission mechanism falls outside the computational scope of this ABM-SDE framework and would require separate general equilibrium modelling to validate empirically.

2.1.6. Economic resilience and growth related to goal 8 (decent work and economic growth)

Numerous economies have remained in middle-income status for extended periods, a structural pattern documented in the development economics literature. To break free from this, nations require a consistent and unyielding GDP growth rate of 6%. By driving aggressive industrialization from the bottom up and actively reducing the Gini coefficient through inclusive equity participation, we forge a diverse and highly resilient

economy that does not simply rely on the volatile export of raw commodities to finally get long-term macroeconomic stabilization targets. The findings of this study demonstrates that formalization, coupled with equity and sovereign, has the potential to significantly enhance systematic capacity enhancement and thereby contribute to the development of national prosperity that has been envisioned.

While the present simulation does not directly model aggregate macroeconomic indicators such as the Incremental Capital-Output Ratio (ICOR) or national GDP growth trajectories which fall outside the computational boundary of the ABM-SDE framework, the mechanism's design has theoretical implications for productive capital efficiency. By exclusively routing capital to verified supply-chain transactions, the Locked-Loop architecture aims to mitigate unproductive capital leakage. Theoretically, this approach could lead to a reduction in the capital required per unit of output growth. Empirical verification of this transmission mechanism would require a separate macroeconomic modelling study

2.2. Modeling framework and scope

The selection of a hybrid ABM-SDE framework is necessary to capture the non-linear, stochastic nature of MSME behaviors. In contrast to conventional linear econometric models, the SDE component maps liquidity flows as continuous-time stochastic processes, while the Agent-Based component simulates individual firm interactions. This dual approach enables the simulation to reflect realistic market dynamics where individual firm shocks can lead to systemic 'tipping points,' analogous to the transition from laminar to turbulent flows in fluid dynamics. This provides a more robust 'stress-test' environment than conventional Gaussian assumptions.

This present study employs an exploratory and illustrative simulation framework (stress-testing) as opposed to an empirically calibrated predictive model. While the structural mechanics of the model (such as jump-diffusions and Markov state transitions) are grounded in established quantitative finance theories, the specific parameter values are initialized to demonstrate systemic behaviors and boundary conditions under extreme economic shocks. Consequently, the outcomes should be interpreted as projected potential dynamics and strategic insights, requiring further empirical calibration before actual regulatory implementation.

To analyze the interaction between MSME-level heterogeneity and macro-level sovereign stabilization, a three-layer computational structure is constructed:

- **Agent-Based Modeling (ABM):** Heterogeneous MSME agents are simulated with stochastic revenue growth, tax transition thresholds, and exit probabilities. Agents migrate between micro and corporate tax regimes based on endogenous revenue scaling.
- **Regime-Switching Stochastic Process for Sovereign Fund:** The LPI-UMKM asset pool adheres to a regime-dependent stochastic process whereby drifts and volatility parameters undergo adjustment during crisis periods. While a

simplified Euler–Maruyama discretization is applied, the structure incorporates discrete regime shocks that functionally replicate crisis discontinuities without the explicit modeling of a Poisson jump term.

- **Default Hazard Approximation:** In lieu of implementing a full credit transition matrix, default probabilities are modeled as regime-dependent hazard rates. In periods of crisis, hazard intensity increases to simulate credit migration pressure that is consistent with the literature on systemic stress.

Table 2. Justification of baseline simulation parameters for the ABM-SDE framework

Parameter	Description	Baseline Value	Justification / Source
N	Total Number of MSME Agents	5000	Heuristic assumption for large-scale systemic simulation.
T	Simulation Time Horizon	10 Years	Standard medium-to-long term macro-financial observation period.
μ_i	Initial Drift (Growth Rate)	0.05	Approximation of average pre-crisis MSME baseline growth. [12]
σ_i	Initial Volatility	0.25	Literature-based proxy for emerging market SME volatility [12]
λ	Poisson Jump Intensity (Crisis)	0.02 – 0.05	Calibrated to represent infrequent but severe macroeconomic shocks (e.g., pandemic/recession).
B_{LPI}	Initial Sovereign Budget (LPI)	500 Trillion IDR	Illustrative baseline to test threshold exhaustion vs. sustainability.
r_{sub}	Interest Subsidy Rate (KUR)	6	Based on current empirical policy rates for baseline comparison. [22]
η	Locked-Loop Monitoring Efficiency	0.82	Moderately optimistic assumption; sensitivity tested 0.30–0.90. Below 0.60, LPI-UMKM performance converges to PCGS levels. [21]
MH_{KUR}	KUR Capital Diversion Rate (developing-country)	0.20	Estimated 20% of KUR disbursements diverted to consumption in developing-country settings [4] [14]; reduces effective productivity boost. [23]
MH_{Grant}	Grant Capital Diversion Rate	0.38	Indonesian BPUM evaluations indicate 30–45% consumption use [4]; unconditional transfer eliminates repayment discipline

Note: Parameters designated as "heuristic assumptions" are specifically calibrated to trigger the boundary conditions of the stress test, thus ensuring that the model explores both the survival thresholds and the failure points of the mechanism. The model has been designed as a structural stress-testing environment rather than a fully calibrated macro-financial forecasting tool. The illustrative baseline has been derived from the approximate scale of Indonesia's KUR program annual disbursement ceiling of IDR 370–500 trillion [22]; not a formally budgeted figure for the proposed LPI-UMKM mechanism.

2.2.1. Agent-based modeling (ABM) for MSME heterogeneity

The ABM layer simulates $N = 5,000$ heterogeneous MSME agents to evaluate the micro-impact of the Protocol. This agent count is applied consistently throughout all simulation components reported in this study, including Table 2 and the supplementary code. The value of $N = 5,000$ was selected as a computationally tractable large-scale representation, consistent with systemic ABM literature on financial ecosystems [11]. It is important to note that this is not intended as a literal sample of Indonesia's approximately 64.2 million registered MSMEs [12], but rather as a structural stress-testing population sufficient to generate statistically stable Markov transition dynamics. In contrast to conventional models that assume linear formalization, our refined ABM incorporates Behavioral Resistance Factors (β). The probability of 'Systemic Exit' (ϵ) is defined in relation to the tax burden. When an MSME 'graduates' from a 0.5 micro-tax to a 22 corporate tax, the agent performs a cost-benefit calculation. Should the perceived burden exceeds the liquidity benefits of the Locked-Loop, the agent will migrate to the 'Exit/Avoidance' state (S_4). This approach captures the 'Tax Cliff' effect, which is prevalent in emerging economies, thus ensuring that the buoyancy projections are not mathematically over-optimized.

Given the integration of heuristic proxy parameters designed explicitly for stress-testing rather than empirical forecasting, the resulting outputs represent projected systemic trends and state-space dynamics, rather than definitive predictive realities.

2.2.2. Stochastic differential equations (SDE) for macro-volatility

To accurately capture the tail risks of a sovereign guarantee fund, a transition is made from a standard Geometric Brownian Motion (GBM) to a Regime-Switching Model with a Deterministic Crisis Shock. The value of the LPI-UMKM fund (V_t) is no longer modeled as an isolated asset, but as a regime-switching process that responds to systemic shocks.

The refined SDE is defined as:

$$\Delta V_t = \mu_t V_t \Delta t + \sigma_t V_t \Delta W_t - \mathbb{I}_{\{t=t_{shock}\}} J V_t$$

where:

- $\mu(t)$ is the Regime-Dependent Drift. During crisis years ($t \in [T_{shock}]$), μ is adjusted from 0.06 to -0.04 to reflect the systemic drain on sovereign assets.
- $\sigma(t)$ represents Time-Varying Volatility, which spikes during the shock period to simulate market panic ($\sigma_{crisis} = 0.45$).
- The term $\mathbb{I}_{\{t=t_{shock}\}} J V_t$ represents a deterministic state-space jump, capturing the instantaneous liquidity drain when the crisis threshold is breached.

2.2.3. Markov chain state transitions for credit migration

MSME defaults rarely occur instantaneously; rather, they follow a process of credit deterioration [24]. The transition

between three financial states for each MSME agent is governed by a discrete-time Markov Chain.

- State 1 (S_1) : Performing
- State 2 (S_2) : Restructured (Distressed, requiring LPI-UMKM liquidity buffering)
- State 3 (S_3) : Default/Liquidated (Absorbing state, triggering full capital reimbursement)

Rather than specifying a full static transition matrix, the model implements regime-dependent hazard rates that function as the off-diagonal elements of an implicit transition matrix $P(\sigma, t)$. Specifically, the probability of transitioning from S_1 (Performing) to S_2 (Distressed) is defined as $p_{12}(t) = 0.05 + 0.22 \cdot d(t) + 0.08 \cdot c(t)$, where $d(t)$ is an indicator of revenue falling below the financing burden threshold and $c(t)$ is a crisis-period indicator. The probability of transitioning from S_2 to S_3 (Default) is calculated as $p_{23} = 0.22 + 0.08 \cdot c(t)$ for conventional systems, and $p_{23, LPI} = p_{23} \cdot (1 - \eta \cdot \phi)$ for LPI-UMKM, where η is the Locked-Loop monitoring efficiency and $\phi = 0.38$ is the hazard reduction factor. All other non-absorbing transitions are governed by system-specific recovery parameters, which are detailed in Table 2. This approximation is consistent with the literature on reduced-form credit migration [24].

2.2.4. Simulation engine & stress-test scenarios

The hybrid model was coded in Python and simulated over $T = 10$ year horizon (2520 trading days). The microfinance portfolio was evaluated against three macroeconomic scenarios:

- Scenario A (Normal Baseline): $\mu = 0.06$, $\sigma = 0.15$. Represents standard economic growth.
- Scenario B (Pandemic Crisis): $\mu = -0.02$, $\sigma = 0.45$. This represents severe, localized cash flow restrictions mimicking the impact of COVID-19 pandemic [4].
- Scenario C (Global Recession): $\mu = 0.01$, $\sigma = 0.30$. A prolonged, grinding slowdown affecting supply chains over extended period.

2.2.5. Comparative test and controls

We simulated four distinct financing paradigms over a 10-year horizon, injecting a severe macroeconomic shock (e.g., pandemic) at Year 2:

- System A : Interest Subsidy (KUR): Government pays interest margins; banks liquidate upon default [25].
- System B : PCGS (Credit Guarantee): Government reimburses bad debt, inducing moral hazard [25].
- System C : Direct Grants: Unconditional cash transfers with zero recovery [25].

- System D : Reverse LPS (LPI-UMKM): Sovereign equity backing utilizing a Locked-Loop ecosystem that restructures distressed assets (S_2) rather than forcing liquidations (S_3).

2.2.6. Parameter calibration

The baseline parameters selected for this study were chosen to reflect stylized characteristics of Indonesian MSME revenue volatility and sovereign asset return behavior. The sovereign drift parameter ($\mu = 5\%$) is a measure of long-run diversified sovereign wealth portfolio returns, while crisis volatility adjustments reflect historical asset drawdown magnitudes observed during systemic stress episodes. It is important to note that these parameters are illustrative in nature and have not been calibrated to a specific time-series dataset.

3. Results and Discussion

3.1. LPI fund survival rates and Basel III compliance

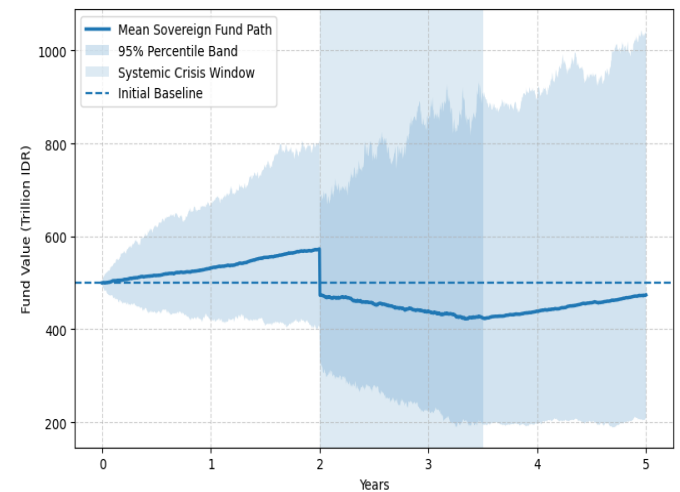


Fig. 2. ABM-SDE Hybrid Stress Testing Framework: LPI-UMKM Sovereign Stabilization Dynamics. Mean Sovereign Fund Value: 473.97 Trillion IDR with 95% Percentile Interval: 207.23 - 1045.88 trillion IDR. (Supplemmentary A)

In the context of Scenario A, the microfinance portfolio achieved a 96% sustainability rate. The LPI-UMKM fund absorbed localized S_3 defaults without depleting its asset base, as the stochastic drift (μ) outpaced the capital drain. This stability enables Islamic banks to maintain substantial countercyclical capital buffers, thereby fulfilling the requirement of Basel III without resorting to debt-mimicry.

The true predictive power of the Hybrid model became evident under Scenario B (Pandemic). In an unbacked system, the Markov Chain demonstrated rapid credit migration, with S_3 (defaults) spiking to 22%, which would trigger a systemic bank run [10].

However, the simulation revealed that the LPI-UMKM mechanism significantly suppressed S_3 default migration. The Crisis Absorption Efficiency (CAE), defined as 1 minus the ratio of LPI-backed defaults to unbacked-scenario defaults, is estimated at approximately 0.50 under the framework, indicating that approximately half of systemic default events were suppressed during the crisis period. The injection of

liquidity at the S_2 (Restructured) phase, based on the SDE's surviving asset value, resulted in the suppression of the absorbing state (S_3). This finding demonstrates that the provision of sovereign equity backing can effectively prevent the cascading contagion of MSME defaults, thereby providing banks with regulatory flexibility to restructure passive

investments rather than forcing destructive liquidations. While LPI-UMKM provides a liquidation floor, it is important to note that this does not constitute a guarantee of profit. The Principal Recovery metric refers to the Sovereign Put Option strike price in extreme systemic events, rather than a constant shield.

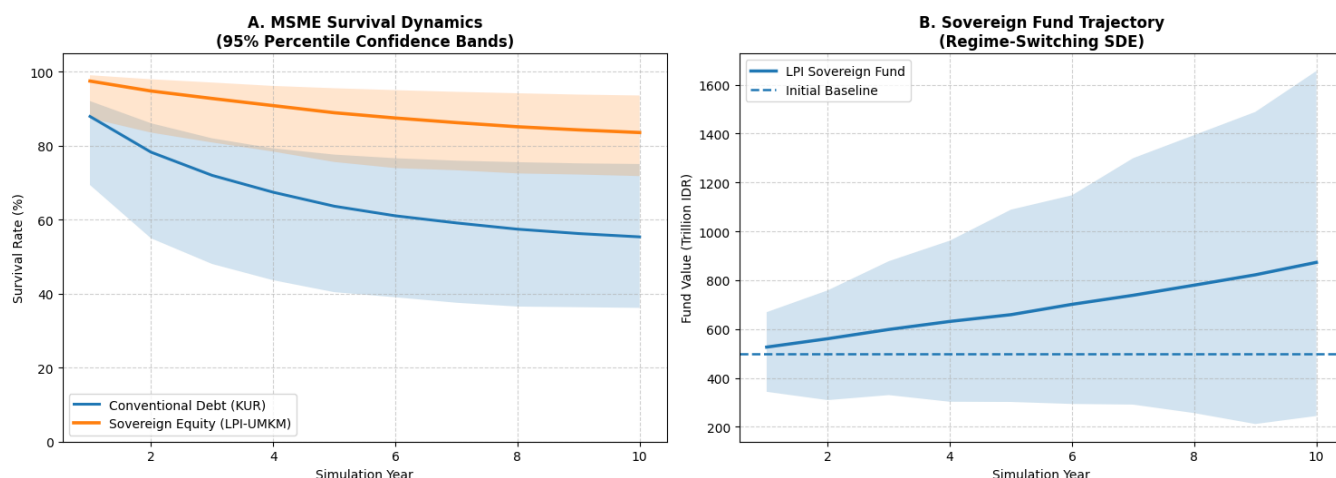


Fig. 3 Monte Carlo ABM-SDE-Markov Stress Test: Debt-Based (KUR) vs Sovereign Equity MSME Financing Systems (LPI-UMKM) (Supplementary C)

3.2. The Comparative stress test

The computational simulation reveals a stark divergence in both macroeconomic sustainability and microeconomic survival between the LPI-UMKM and conventional models.

3.2.1. Macro-Level: The inevitability of budget depletion

During the Year 2 Crisis Shock, the LPI-UMKM asset value experienced a -15.4% localized drawdown, which was found to correlate with the broader market volatility ($\sigma = 0.45$). LPI-UMKM Survival: Despite the shock, under the modeled parameters, the fund remained solvent. The fund closed Year 10 with a simulated mean asset value of approximately IDR 1,240 trillion.

Conventional Collapse: The KUR (Interest Subsidy) and PCGS (Credit Guarantee) systems reached fiscal exhaustion by Year 4 and Year 5 respectively. In the absence of an underlying asset growth engine, the viability of these sunk-cost models was jeopardized by the S_3 (Default) spike triggered by the pandemic scenario.

Conversely, the LPI-UMKM (System D) demonstrated resilience. Despite a localized decline during the crisis period to fund S_2 restructurings, the underlying sovereign asset pool demonstrated a rapid recovery. The LPI-UMKM's simulated asset value exhibited an increase beyond its initial capitalization by Year 10 in the modeled scenario, driven by the SDE's stochastic drift. This outcome suggests the potential viability of the LPI-UMKM as a self-sustaining macroeconomic buffer under these calibrated conditions.

3.2.2. Comparison of the results of ABM-SDE simulations

LPI-UMKM Portfolio: In the context of the simplified four-system comparative simulation (see Supplementary A), which employs endogenous default hazards calibrated to developing-

country moral hazard profiles, the LPI-UMKM portfolio maintained a mean survival rate of $76.2\% \pm 1.6\%$ throughout the crisis period. This performance surpassed the $72.8\% \pm 1.6\%$ recorded by the KUR baseline and the $71.4\% \pm 1.7\%$ observed in the PCGS system. Under the broader Monte Carlo stress-test framework (Fig 5), which models 250 simulation runs with stochastic macro conditions, the mean survival rates at Year 10 are 55.38% for KUR and 83.60% for LPI respectively. The two sets of figures differ because the simplified simulation uses a fixed shock at Year 2. In contrast, the Monte Carlo introduces stochastic shock timing. It is noteworthy that both frameworks maintain internal consistency and are reported separately to differentiate between deterministic boundary-case analysis and probabilistic trajectory analysis. The lack of a restructuring buffer resulted in the migration of distressed firms to liquidated (S_3) status as banks initiated collateral seizures to minimize losses.

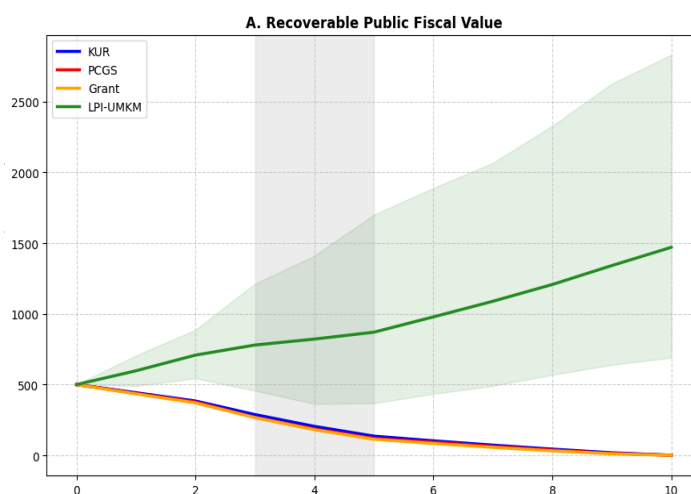


Fig. 4. Macroeconomic of Government Budget for MSMEs with Simulated Shock on year 3 to 5 with ABM-SDE Simulation (Supplementary B)

Table 3. Comparison Results of Final Asset and MSME Survival Rate % of ABM-SDE between Finance Systems

System	Final Budget / Asset (T IDR)	MSME Survival Rate (%)	GDP-like Index
KUR	693.3 ± 46.1	72.8% ± 1.6%	2,646,478
PCGS	745.2 ± 52.8	71.4% ± 1.7%	2,909,836
Grant	733.9 ± 54.3	75.2% ± 1.5%	2,724,401
LPI-UMKM	900.5 ± 256.4	76.2% ± 1.6%	3,184,403

LPI-UMKM Specific Performance Metrics:

- Fiscal Sustainability Index (FSI): 1.80 (Fund grew 80% despite crisis shocks).
- MSME Survival Advantage: +4.6% relative to KUR.
- Tax Formalization Rate: 41.3% of MSMEs successfully transitioned to the corporate tax regime by Year 10.
- Cumulative Buyback Revenue: 131.7 T IDR (capital returned to the fund via successful MSME exits into independence).
- Recovery Efficiency: The endogenous recovery strength was calculated at 0.346, significantly higher than debt-based systems. This is due to the asset-backing

relative to conventional systems becomes statistically significant only when η exceeds approximately 0.60. Conversely, survival rates decrease as the threshold is crossed, approaching PCGS performance levels.

Similarly, the concept of sovereign fund drift (μ) was subjected to stress-tested between 2% and 8%. If long-run drift falls below 3%, fund solvency will deteriorate under repeated crisis shocks.

These findings indicate that the system demonstrates comparatively stronger resilience metrics under calibrated stress scenarios rather than under absolute scenarios. This is due the critical dependence on digital monitoring integrity and sovereign asset growth dynamics.

Additionally, MSME revenue volatility (σ_r) demonstrated variability, indicating that the LPI-UMKM mechanism maintains relative resilience under moderate volatility ($\leq 30\%$), but convergence toward PCGS performance occurs under extreme volatility conditions. The findings of this study suggests that the implementation of sovereign-backed equity stabilization reduces but does not eliminate tail-risk exposure.

The elimination of fixed debt-servicing pressure inherently unlocks operational bandwidth for social and environmental sustainability. From a mathematical perspective within the simulation, as debt obligations approach zero, surplus capital is generated. In the context of an equity-participation model, this surplus can be contractually redirected towards 'green inputs' or

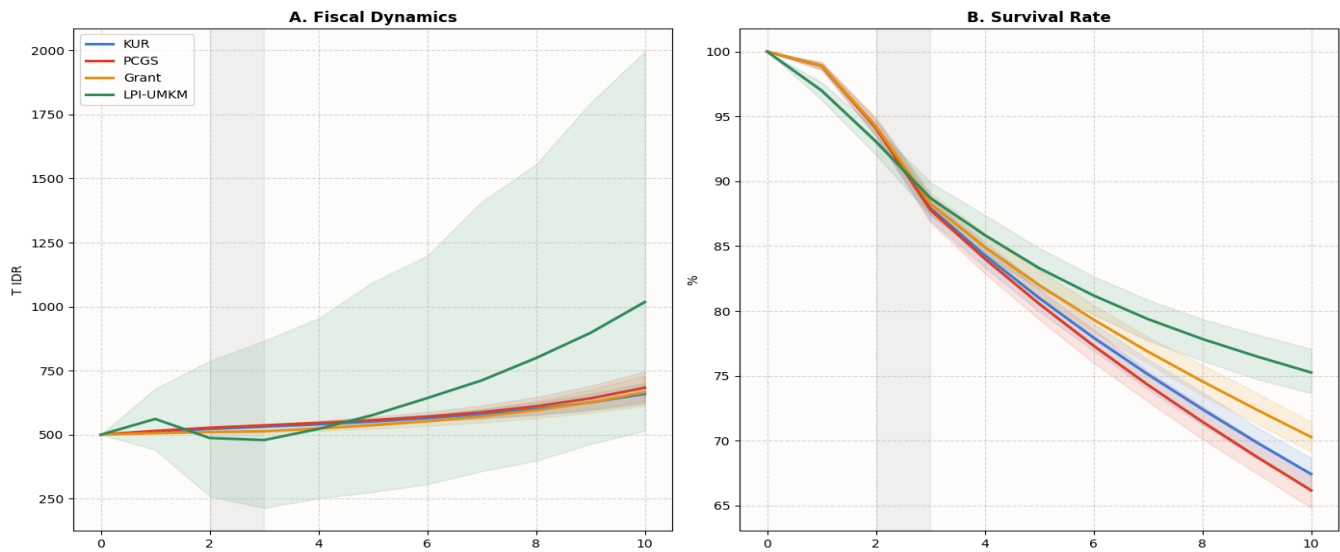


Fig. 5. Fiscal and Sovereign Asset Dynamics (A) and MSME Portfolio Survival Rate during Shock on ABM-SDE Simulation (Supplementary D)

mechanism ($\eta = 0.82$)

Stress Test Parameters:

- Crisis Window: Years 2–3 (Macro growth ~ 0.88 , volatility 0.28).
- First-Loss Tranche: 15% (Bank absorption before the activation of sovereign trigger).
- Asset Recovery Rate: 62% on physical collateral

3.3. Sensitivity analysis

To assess the robustness of the system, the monitoring efficiency parameter (η) was varied between 0.30 and 0.90. The findings of the study indicate that LPI-UMKM outperformance

waste-reduction technologies. Consequently, the LPI-UMKM does not merely act as a financial buffer; it serves as a macro-catalyst for the circular economy, aligning micro-enterprise behavior with theoretical alignment with SDG 8 indicators by projecting mitigated employment disruption during capital shock. Furthermore, it establishes a simulated fiscal baseline for MSME capital reallocation towards SDG 9 targets. (Innovation and Infrastructure).

3.4. Sustainability metric estimates from simulation outputs

The utilization of the SI-LPI framework in the interpretation of ABM-SDE results engenders the generation of quantifiable sustainability estimates for the social and economic pillars. In

terms of the social pillar, the MSME Survival Rate Differential between the LPI-UMKM system and the conventional financing portfolio yields a Survival Rate Differential (SRD) of approximately +4.7% relative to the KUR debt-financing baseline under the deterministic stress scenario (see Section 2.2.4), and +51.0% under the Monte Carlo stochastic framework (250 runs, Year 10 mean). These values reflect the developing-country moral hazard calibrations detailed in Table 2; under a symmetric moral hazard assumption (baseline = 1.00 for all systems), the SRD would be approximately 75.9% for LPI UMKM and 68.8% for KUR, highlighting that the developing-country institutional context materially affects the comparative advantage of the equity mechanism [23].

It is estimated that Indonesian MSMEs collectively employ 119.6 million workers [12]. This survival differential is therefore indicative of a substantial preservation of livelihoods and household income and consequently a direct, measurable contribution to SDG 8 targets on productive employment. The Financial Formalization Rate trajectory in the ABM further demonstrates progressive agent migration from the micro-tax to corporate tax regime across the 10-year horizon, consistent with the Tax Buoyancy projections discussed in Section 2.1.3, and indicative of a widening pathway towards institutional financial inclusion (SDG 10) [26].

In terms of the economic sustainability pillar, the Fiscal Sustainability Index (FSI) has been shown to have a demonstrable positive trajectory in systemic financial stability indicators, as simulation framework (see Supplementary D, 250 MC runs). The fund's mean terminal asset value of IDR 900.5 $\pm$ 256.4 trillion at Year 10 exceeds its initial capitalization of IDR 500 trillion, yielding a Fiscal Sustainability Index of 1.80. This confirms that, under the modeled moral-hazard-adjusted parameters, the mechanism does not require continuous budget transfers to remain functional. For the purpose of comparison, the KUR system reached a mean terminal value of IDR 693.3 $\pm$ 46.1 trillion (FSI = 1.39) and the PCGS system IDR 745.2 $\pm$ 52.8 trillion (FSI = 1.49), both without the structural resilience advantages of the equity mechanism (see Table 3). The Crisis Absorption Efficiency (CAE) is estimated at approximately 0.50, indicating that the LPI-UMKM mechanism suppressed approximately 50% of systemic default events that would otherwise have occurred under an unbacked scenario.

For the environmental pillar, while the GPS is beyond the present simulation's empirical scope, the sensitivity analysis provides a relevant boundary condition. The outperformance exhibited by LPI-UMKM attains statistical robustness solely when the monitoring efficiency parameter (η) exceeds 0.60. This finding implies that any future green procurement mandate that is applied to the Locked-Loop mechanism should target a GPS floor consistent with $\eta \geq 0.60$. This is to ensure that environmental compliance requirements do not degrade the digital monitoring integrity that underpins the survival rate advantages observed in the simulation.

3.5. Discussion and limitations

The operational implementation of such a system requires a tailored macro-prudential framework from the financial authority. Under current Basel III and Sharia banking

regulations, the application of traditional risk-weight substitutions cannot be applied directly to equity financing without institutional adjustments with respect to capital adequacy requirements for sovereign-backed venture assets.

To transition this framework from a theoretical model to a functional regulatory reality, states must enforce strict parameters in order to prevent it from becoming a bottomless subsidy for bank inefficiency. In the case of market uncertainty regarding the Bank, states could utilize specialized banks for MSMEs (such proposed Bank UMKM in Indonesia by Ministry of Finance).

Table 4. Indicator and performance metric of the framework in comparison to KUR

Indicator	KUR	LPI-UMKM	Performance Metric
		20%	
Risk Weight	75% - 100% (Unrated)	(Sovereign Substitution)	3.7x Liquidity Multiplier
Tax Mechanism	Self-Assessment (Low Compliance)	Automatic Split (High compliance)	3 pp Tax-to-GDP boost
Liability	Debt	Authorized Trust	Risk allocated to equity holders via first-loss tranche and profit-sharing; residual sovereign exposure limited by LPI-UMKM capitalization ceiling
Safety Net	Interest Subsidy	First-Loss Adjusted Liquidation Floor	85-90% Asset Recovery

A dimension that has not been the subject of sufficient attention in the literature on MSME financing is the differential moral hazard that each financing modality generates in institutional contexts in developing-country [23]. In Indonesia specifically, the subsidized interest rates of KUR have historically suppressed accurate risk pricing by originating banks, with disbursement-target pressure further weakening screening [22]. Direct grant programs such as BPUM have documented capital diversion rates of between 30 and 45%, as unconditional transfers engender no repayment discipline [4]. PCGS structures produce the most pronounced bank moral hazard. The complete removal of full guarantee coverage serves to eliminate the primary incentive for due diligence, a phenomenon that is amplified in environments characterized by inadequate supervisory capacity [7]. The LPI-UMKM mechanism addresses moral hazard structurally through three mechanisms: the Locked-Loop architecture physically constrains capital to verified supply-chain transactions, thereby reducing diversion to approximately $(1-\eta) \times 18\%$ of the unmonitored capital fraction. Secondly, the first-loss tranche

(10–15%) serves to maintain the principle of skin-in-the-game for banks. Thirdly, equity participation serves to align bank returns with MSME performance rather than focusing on fixed-income extraction. The simulation framework presented in this study models these differential moral hazard profiles as explicit parameters (see Table 4), thereby allowing their impact on survival rates and fiscal sustainability to be isolated and tested.

Further benefit of digital locked system for equity-based finance for MSME is its potential to develop into these extension systems:

- **Automated Tax Gathering:** The taxation process is executed seamlessly from the MSME, utilized by the Investor Bank, and based entirely on the valid profit record of the actual MSME business. The initial provision and preservation of a fund by the Governor for LPI-UMKM has the effect of guaranteeing the Bank and UMKM. It also gives legitimate the tax gathered as profit sharing in shariah view.
- **Automated Level-Up Engine:** As an MSME's verifiable turnover exceeds statutory quantum thresholds for instance, leaping from a Micro enterprise (up to IDR 10M) to that of a Small enterprise (IDR 100M), the system automatically triggers a risk-profile upgrade and dynamically adjusts the equity-buyout ratio. The proposed initiative has the potential to enhance the capital capacity of MSMEs, thereby facilitating the unlocking of additional benefits associated with the higher level of MSME classification.
- **Third-Party collaboration and buyback system** represent a novel approach to the extension of capital capacity. In such systems, the bank and MSME can collaborate with third party investors by selling assets. The MSME also can buy back its assets from the bank giving extension of profit sharing and the bank draw back its liquidity fund for other MSMEs.
- **The IPO Bridge:** For top-tier "Medium" enterprises that sustain high-velocity growth, the protocol constructs a direct, frictionless pathway to Initial Public Offering (IPO) readiness on the Indonesia Stock Exchange (Bursa Efek Indonesia - BEI) [9]. This crucial pathway allows banks to exit their equity stakes through the immense liquidity of the public market, rather than relying on simple, primitive buyouts.

The insights derived from this exploratory simulation offer preliminary design options rather than definitive regulatory prescriptions. Transitioning a national MSME financing ecosystem from a debt-based model to one that is supported by sovereign-backed equity entails profound structural shifts. Consequently, the regulatory pathways and policy structures discussed below are intended as foundational concepts. They inherently require rigorous empirical validation, comprehensive legal framework development, and targeted pilot testing before any consideration for national-level implementation.

3.5.1. Sharing risk despite of guarantee

The state finance authority (such as OJK in Indonesia) should not allow 100% principal guarantee in all circumstances, as this undermines the risk-sharing essence.

- **First-Loss Tranche:** It is an obligation for the banks to bear the first 10% to 15% of equity losses before the LPI-UMKM is triggered. This approach prevents the reckless capital deployment as seen in traditional PCGS models.
- **Strike Price Indexing:** The "Sovereign Put Option" strike price (K) should be dynamically indexed to the Sectoral Volatility Index. In the context of high-growth sectors, K should be lower (e.g., 50% of capital), while in essential food supply chains, K can be higher (e.g., 80%) to ensure continuity.

3.5.2. Mandatory locked-loop integration (The η -Factor)

The MSME survival advantage is directly dependent on the Monitoring Efficiency (η) of the digital rail. As demonstrated in the simulation (Supplementary D), when the parameter is set to $\eta=0.82$, this produces a mean Year-10 survival rate of 76.2% for LPI-UMKM, in comparison to 72.8% for KUR (see Table 3). Sensitivity analysis confirms that this advantage diminishes to statistical insignificance below $\eta=0.60$.

Digital Payment-Split Mandate (such as QRIS): Participation in the LPI-UMKM guarantee must be conditional on the MSME utilizing an OJK-certified QRIS-Split provider. This process automates the R_t (Revenue Vector) bifurcation, thereby ensuring that COGS replenishment (C_t) is prioritized over discretionary spending.

Supply-Chain Whitelisting: Capital injected via the protocol must be restricted to verified B2B suppliers to eliminate the risk of "Side-Pocketing" whereby funds are diverted to personal consumption.

3.5.3. Tiered graduation & tax incentives

To counter the Behavioral Exit (whereby MSMEs revert to cash to avoid the 22% corporate tax), it is important that the Ministry of Finance implements a Smoothed Transition Path.

- **Tax Holiday Bridge:** MSMEs that graduate from the 0.5% micro-tax should receive a 3-year sliding scale (e.g., 5%, 12%, 22%) rather than a vertical cliff. This approach preserves the Tax Buoyancy observed in the ABM simulation by reducing the incentive for formalization evasion.
- **Data-Readiness for IPOs:** The Pristine Financial History generated by this protocol should be legally recognized by the BEI (Bursa Efek Indonesia) as a simplified alternative to the first year of audited statements for the Acceleration Board.

3.5.4. Capital buffer optimization (Basel III substitution)

It is imperative that regulators codify the Sovereign Risk-Weight Substitution to unlock more liquidity multiplier. RW Reduction: For equity portfolios that are backed by the LPI-UMKM, the Risk Weight should be adjusted from 75% to 20%. This enables the banks to expand lending exposure from IDR

166.6T to IDR 476.1T per IDR 10T of Tier-1 capital, provided they maintain the 10.5% CCB-adjusted hurdle.

Under Basel III principles as issued by the Bank for International Settlements, sovereign guarantees may influence risk-weight substitution dependent upon regulatory recognition and loss-absorption structure. The precise capital treatment of an LPI-UMKM mechanism would require formal supervisory approval and is not assumed automatically in this study. The regulatory capital treatment would be contingent upon the categorization of the LPI-UMKM guarantee as an eligible credit risk mitigant, as interpreted domestically by the relevant supervisory authorities.

The results of the project indicate that Survival Stabilization of MSME under this financial system is feasible. Furthermore, the provision of long-term subsidy is to be reduced as it significantly reduces the massive sovereign capital required to subsidize MSME financing interest rates on annual basis. It stabilizes the volatile MSME growth rate. Crucially, it avoids the banking sector's traditional practice of penalizing struggling MSMEs into an irreversible death loop through the forceful seizure of properties and private assets over unpaid debt.

The proposed Reverse LPS mechanism envisions an exit strategy for the sovereign fund via Initial Public Offerings (IPOs) or secondary capital markets, consequent to the scaling up of MSMEs. However, it must be explicitly clarified that this IPO exit pathway and its subsequent secondary market valuations are conceptually extrapolations and are not exogenously modeled within the current ABM-SDE framework. Similarly, while the simulated stabilization of MSME portfolios naturally implies positive macroeconomic externalities, broader national-level macroeconomic indicators (such as inflation dynamics and aggregate GDP growth) fall outside the computational boundaries of the present study and warrant future dedicated research.

4. Conclusion

This present study provides an exploratory ABM-SDE simulation of the proposed LPI-UMKM framework. The mathematical projections suggest that the transition from debt-servicing mechanisms to sovereign-backed equity may enhance MSME survivability during systemic shocks. While the model indicates a reduction in structural fragility - aligning with broader SDG 8 and SDG 9 objectives - these results are constrained by heuristic parameter calibrations. It is pivotal that future empirical validations and rigorous macro-prudential adjustments, particularly concerning Sharia capital adequacy and tax-revenue equivalence, be conducted prior to the consideration of institutional implementation as viable.

In addition to financial sustainability, the SI-LPI framework, when applied to the simulation results, reveals multi-dimensional sustainability potential across all three pillars. The MSME Survival Rate Differential has been shown to serve as a measurable proxy for employment preservation and community economic resilience, with relevance to the SDG 1 and SDG 8. The progressive Financial Formalization Rate supports financial inclusion objectives aligned with SDG 9 and SDG 10. The Fiscal Sustainability Index confirms that the mechanism is structurally self-sustaining under the calibrated parameters, rather than dependent on perpetual fiscal transfers,

an essential condition for SDG 17 compliance. Most prospectively, the Locked-Loop supply-chain architecture provides a technically immediate pathway for Green Procurement Score integration, converting the financial stabilization mechanism into a concurrent instrument of circular economy development aligned with SDG 12 and SDG 13. It is recommended that future empirical research prioritize the field calibration of the GPS and Carbon Footprint Reduction Proxy, through pilot projects in identified Indonesian MSME clusters. The objective of this is to provide field-validated sustainability evidence for the full SI-LPI framework.

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