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Evolutionary Dynamics of Tax Compliance Under Institutional Trust

Kurumsal Güven Çerçevesinde Vergi Uyumunun Evrimsel Dinamikleri

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ABSTRACT

This study investigates the evolutionary dynamics of tax compliance in an agent-based Public Goods Game (PGG) framework, where institutional trust (T) conceptually informed by the World Bank Governance Indicators (WGI) enters as an exogenously specified parameter that modulates the perceived return to public good provision We develop an Agent-Based Model (ABM) using the Mesa framework, where institutional trust (T) modulates the perceived return on public goods, thereby affecting the evolutionary payoff of compliant agents. Simulation results demonstrate that institutional trust acts as a strategic complement to deterrence. In high-trust environments (T=0.8), high compliance rates ($PC^* > 0.9$) are achieved with minimal enforcement effort, while low-trust environments (T=0.2) require disproportionately high fine rates ($f > 8.0$) to maintain even moderate compliance. The findings provide a dynamic validation of the Slippery Slope Framework, showing that the effectiveness of coercive power is fundamentally mediated by institutional legitimacy. The study concludes that prioritizing governance quality is the most efficient long-term strategy for fostering stable tax compliance, shifting the policy focus from mere deterrence to building a robust social contract.

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ÖZ

Bu çalışma, kurumsal güven ve cezalandırmanın etkisi altında vergi uyumunun birlikte evrimsel dinamiklerini incelemekte; mikro düzeydeki Kamu Malları Oyunu'nu (Public Goods Game, PGG), Dünya Bankası Yönetişim Göstergeleri (WGI) ile temsil edilen makro düzey kurumsal kaliteyle bütünleştirmektedir. Mesa çerçevesi kullanılarak geliştirilen Ajan

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Tabanlı Model'de (Agent-Based Model, ABM), kurumsal güven (T), kamu mallarına ilişkin algılanan getiriyi düzenleyerek uyumlu ajanların evrimsel getirilerini etkilemektedir. Simülasyon sonuçları, kurumsal güvenin caydırıcılığa stratejik bir tamamlayıcı olarak işlediğini göstermektedir. Yüksek güven ortamlarında (T=0.8), düşük düzeyde uygulama çabasıyla yüksek uyum oranlarına (PC* > 0.9) ulaşılırken; düşük güven ortamlarında (T=0.2) orta düzeyde uyumu koruyabilmek için orantısız derecede yüksek ceza oranları (f > 8.0) gerekmektedir. Bulgular, zorlayıcı gücün etkinliğinin esasen kurumsal meşruiyet tarafından belirlendiğini göstererek "Kaygan Zemin Çerçevesi"nin dinamik bir doğrulamasını sunmaktadır. Çalışma, yönetişim kalitesine öncelik vermenin uzun vadede istikrarlı vergi uyumunu teşvik etmede en etkili strateji olduğunu ve politika odağının yalnızca caydırıcılıktan güçlü bir toplumsal sözleşme inşasına kaydırılması gerektiğini ortaya koymaktadır.

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1. INTRODUCTION

1.1. Background and Motivation

Tax compliance stands as a cornerstone of modern state functionality, directly influencing the capacity of governments to fund public goods and services essential for economic stability and social welfare (Slemrod, 1992). The study of tax compliance has historically been dominated by the Deterrence Theory, rooted in the seminal work of Allingham and Sandmo (1972). This framework posits that taxpayer behavior is a rational economic decision, where compliance is determined by the expected utility derived from weighing the benefits of evasion against the probability of detection and the severity of penalties. Consequently, policy prescriptions have largely focused on increasing audit rates and fine magnitudes to enforce compliance.

However, the empirical evidence often suggests that the high levels of tax compliance observed in many developed nations cannot be fully explained by the relatively low audit probabilities and moderate penalties alone (Alm, 2012). This discrepancy has spurred a significant shift in research focus towards the socio-psychological and institutional factors that underpin voluntary compliance. Among these factors, institutional trust defined as the belief that the government and its associated institutions are competent, fair, and acting in the public interest has emerged as a critical determinant (Torgler, 2007). When citizens trust their government, they are more likely to view taxation as a legitimate social contract rather than a coercive imposition, thereby increasing their intrinsic motivation to comply.

1.2. Research Gap

The existing literature, while rich, presents two distinct streams that have yet to be fully integrated, creating a significant research gap.

First, the application of Evolutionary Game Theory (EGT), particularly the Public Goods Game (PGG), has provided a powerful lens for understanding the dynamic and interactive nature of tax compliance (Bloomquist, 2011). Recent studies have successfully modeled tax compliance as a collective action problem, where the evolution of cooperation (compliance) is sustained through mechanisms like tax-based punishment or reward (Li et al., 2022; Shen et al., 2023). These models, often employing Replicator Dynamics, focus on the internal dynamics of strategy adoption but typically treat the institutional environment (e.g., the tax authority's behavior) as a fixed, exogenous parameter.

Second, a large body of empirical and behavioral research has established a robust link between institutional quality (often measured by indicators like the World Bank Governance Indicators, WGI) and tax compliance (Pickhardt & Prinz et al., 2014; Gangl et al., 2015). This research often utilizes the Slippery Slope Framework, which conceptualizes tax compliance as a balance between power (deterrence) and trust (voluntary compliance) (Kirchler et al., 2008). While insightful, these studies are primarily static or cross-sectional, lacking the capacity to model the dynamic, non-linear feedback loops between institutional quality and taxpayer behavior over time.

The critical gap lies in the absence of a dynamic, agent-based model that endogenously links a measurable, real-world proxy for institutional trust (such as the WGI) to the evolutionary dynamics of tax compliance within a PGG framework. Current EGT models lack the institutional context, and current behavioral models lack the evolutionary dynamic. This study aims to bridge this gap by developing an Agent-Based Model in which institutional trust motivated by WGI dimensions is introduced as an exogenous governance parameter, enabling a systematic analysis of the evolutionary dynamics of compliance under varying institutional conditions.

1.3. Research Questions and Objectives

This study seeks to address the following core research questions:

1. How does the level of institutional trust, proxied by the World Bank Governance Indicators (WGI), influence

the evolutionary stability and equilibrium level of tax compliance in a Public Goods Game with a punishment mechanism?

2. What is the optimal combination of institutional trust and punishment intensity required to maintain high levels of tax compliance, and how does this relationship manifest in the evolutionary dynamics?
3. Does the interaction between institutional trust and punishment intensity support the predictions of the Slippery Slope Framework within an evolutionary context?

The primary objective is to develop and analyze an ABM, implemented using the Mesa framework, to simulate the long-term evolutionary dynamics of tax compliance. By integrating WGI-derived institutional trust as a variable parameter, the study will provide novel insights into the complex interplay between coercive power and voluntary cooperation in the tax ecosystem, offering evidence-based policy recommendations that move beyond mere deterrence.

1.4. Structure of the Paper

The remainder of this paper is structured as follows. Section 2 reviews the relevant literature on tax compliance, institutional trust, evolutionary game theory, and agent-based modeling. Section 3 details the conceptual framework, the structure of the Agent-Based Model, the integration of institutional trust via WGI, and the simulation setup. Section 4 presents the simulation results, analyzing the evolutionary dynamics under various institutional trust and punishment scenarios. Section 5 discusses the theoretical and policy implications of the findings. Finally, Section 6 concludes the paper and outlines avenues for future research.

2. LITERATURE REVIEW

2.1. Tax Compliance: Deterrence vs. Trust

The traditional economic model of tax compliance, pioneered by Allingham and Sandmo (1972), treats the decision to evade as a straightforward choice under uncertainty. Taxpayers maximize expected utility by comparing the potential gain from evasion with the risk of being audited and penalized. This model, while foundational, has been criticized for its inability to explain observed compliance rates, leading to the development of models incorporating behavioral and psychological factors (Slemrod, 1992).

The shift towards a behavioral perspective introduced concepts such as tax morale and trust as crucial non-pecuniary determinants of compliance (Torgler, 2007). The most influential framework integrating these factors is the Slippery Slope Framework (SSF) proposed by Kirchler et al. (2008). The SSF posits that tax compliance is influenced by two main dimensions: Power (coercive measures like audits and fines) and Trust (voluntary cooperation based on the belief in the tax authority's fairness and competence). High power leads to enforced compliance, while high trust leads to voluntary compliance. The framework suggests that an imbalance such as high power coupled with low trust can lead to a hostile relationship and decreased overall compliance, creating a "slippery slope" towards widespread evasion. This study adopts the SSF as its theoretical anchor, specifically focusing on the dynamic interaction between the power dimension (punishment) and the trust dimension (institutional trust).

2.2. Institutional Trust and Governance Quality

A growing body of research has begun to move beyond purely cross-sectional applications of the SSF. Laboratory experiments and survey-based studies increasingly examine how changes in perceived power and trust over time affect taxpayers' willingness to comply, and how different enforcement styles shape the evolution of the tax authority–taxpayer relationship (e.g., Alm, 2012; Gangl et al., 2015; Luttmer & Singhal, 2014). However, these contributions typically rely on reduced-form empirical designs or short-run behavioral responses, and thus cannot fully capture the long-term, non-linear feedbacks that arise when institutional quality and compliance co-evolve. By contrast, the present study embeds the core SSF dimensions directly into an evolutionary game-theoretic and agent-based framework, allowing us to trace how alternative configurations of power and trust give rise to distinct compliance regimes. In this sense, the model is designed not merely to "illustrate" the SSF, but to provide a dynamic validation of its central claims within a micro-founded and institutionally explicit setting.

Institutional Trust is defined as the confidence citizens place in the integrity, reliability, and competence of governmental and public institutions (Levi, 1998). In the context of taxation, this trust is often linked to the perceived quality of governance, particularly the government's efficiency in providing public goods and its fairness in enforcing laws.

This institutional interpretation of the WGI is closely aligned with the broader literature on tax morale and commons governance. Frey and Torgler (2007) show that taxpayers' willingness to comply depends not only on the expected costs of evasion, but also on whether they perceive the state as a trustworthy and benevolent custodian of collective resources. Similarly, Ostrom's (1990) analysis of self-governed common-pool resources highlights how stable cooperation emerges when formal and informal institutions credibly ensure that individual contributions are transformed into shared benefits and that rule violations are addressed fairly. By focusing on corruption control, rule of law, and government effectiveness, our Trust Index captures precisely those aspects of governance that make such credible commitments possible in modern tax systems. In other words, T should be

interpreted as a macro-level measure of the state's ability to sustain tax morale by delivering high-quality public goods and enforcing rules impartially, rather than merely as a generic indicator of institutional quality.

It is important to stress that, in this paper, institutional trust is conceptualized in a deliberately focused sense. Rather than attempting to capture the full spectrum of citizens' political support or diffuse regime legitimacy, T is anchored in those governance features that most directly affect taxpayers' beliefs about the efficient and impartial use of fiscal resources. In this respect, our approach is closer to an "administrative trust" perspective, which emphasizes the probity, capacity, and procedural fairness of public authorities, than to broader notions of political trust that incorporate partisanship or ideological alignment. This conceptual narrowing is consistent with tax morale research that links compliance primarily to perceptions of corruption control, rule of law, and government effectiveness, as opposed to general satisfaction with democratic procedures. It also prepares the ground for the subsequent operationalization of T through selected WGI dimensions, ensuring that the empirical proxy remains tightly aligned with the theoretical construct that guides our modeling choices.

To operationalize this abstract concept for modeling, researchers frequently turn to macro-level indicators of governance quality. The Worldwide Governance Indicators **(WGI)**, developed by the World Bank (2023a & 2023b), provide a comprehensive measure of governance across six dimensions: Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption (Kaufmann et al., 2011).

For the purpose of linking institutional quality to tax compliance, three WGI dimensions are particularly relevant and will be utilized in this study. Table 1 summarizes the conceptual relevance of the three selected WGI dimensions Control of Corruption, Rule of Law, and Government Effectiveness and explains why these indicators are theoretically appropriate proxies for institutional trust in the context of tax compliance.

As shown in Table 1, these three governance dimensions jointly capture the integrity, fairness, and administrative capacity of the state, thereby forming the core institutional foundations that shape taxpayers' trust and voluntary compliance.

These indicators collectively provide a robust, empirically grounded proxy for the level of institutional trust that taxpayers perceive, which can then be integrated as a key parameter in the agent-based simulation.

2.3. Evolutionary Game Theory and Tax Compliance

Evolutionary Game Theory (EGT) provides a framework for analyzing how strategies evolve in a population over time, driven by the principle of "survival of the fittest" (Smith & Price, 1973). The Replicator Dynamics equation, a core component of EGT, describes how the frequency of a successful strategy increases in the population based on its payoff relative to the average payoff.

The Public Goods Game (PGG) is the standard model used in EGT to study the evolution of cooperation, which is directly analogous to tax compliance (Fehr & Gächter, 2000). In the PGG, individuals choose whether to contribute to a common pool (compliance) or free-ride (evasion). While free-riding is the Nash equilibrium in the one-shot game, cooperation can be sustained through mechanisms like punishment.

Recent studies have applied the PGG with punishment to model tax compliance dynamics. For instance, Li et al. (2022) analyze the replicator dynamics of a public goods game with tax-based punishment mechanisms. Shen et al. (2023) used Replicator Dynamics to show how different punishment strategies (e.g., fines, social reputation) can stabilize compliance. However, these models often assume a fixed institutional context, where the effectiveness of public spending (the multiplication factor in the PGG) and the parameters of the punishment mechanism are static. Our approach differs from the mainstream PGG literature not only in the introduction of a trust parameter, but also in the way institutional quality enters the payoff structure. In many evolutionary models, external punishment or endogenous peer sanctions are modeled as additive payoff components that directly reduce the gains from free-riding. By contrast, the trust-modulated multiplier r′(T) operates as a multiplicative transformation of the public good itself.

Table 1. Operational definitions and relevance of three WGI dimensions for institutional trust in tax compliance

WGI dimension	Relevance to institutional trust and tax compliance
Control of corruption (CC)	Measures the extent to which public power is exercised for private gain. Low corruption directly enhances trust in the fairness of the tax system and the government's integrity (Djayasinga et al., 2019).
Rule of law (RL)	Measures the extent to which agents have confidence in and abide by the rules of society, including the quality of contract enforcement and the courts. High RL ensures that tax laws are applied consistently and fairly, fostering procedural trust (Pickhardt & Prinz., 2014).
Government effectiveness (GE)	Measures the quality of public services, the quality of the civil service, and the degree of its independence from political pressures. High GE ensures that tax revenues are efficiently converted into public goods, reinforcing the social contract (Gangl et al., 2015).

This implies that improvements in governance quality are conceptualized as increasing the productivity of collective contributions rather than merely raising the costs of non-compliance. In this sense, institutional trust functions as an endogenous "reward" mechanism that enhances the relative attractiveness of compliance without altering the formal punishment schedule. This modeling choice allows us to capture a key insight from the tax morale literature: citizens comply not only because evasion is costly, but also because they perceive their taxes as generating tangible and fairly distributed social benefits. The model therefore bridges EGT studies of sanctioning with behavioral accounts emphasizing legitimacy and perceived public good provision.

A simple payoff comparison helps to clarify this distinction. In standard tax-based public goods models, institutional features often enter the payoff as an additive "trust bonus", such that Payoff = … + Trust Bonus, leaving the marginal return to each unit of contribution unchanged. By contrast, in our framework institutional trust modifies the productivity of the public good itself, so that Payoff = … + $r'(T)$ × Contribution, where $r'(T)$ captures how effectively contributions are transformed into collective benefits. When governance quality is poor (low T), the effective multiplier approaches one and even compliant taxpayers receive little surplus from the public good, whereas high-trust environments (high T) amplify the return to cooperation for all group members. This multiplicative specification aligns with the view that institutional performance operates primarily through the credible provision of public goods and the fair enforcement of rules, rather than through ad hoc side payments (Ostrom, 1990; Frey & Torgler, 2007). It therefore provides a more realistic representation of how improvements in governance can reshape the underlying payoff structure of tax compliance. This study extends this line of research by endogenizing the institutional context through the WGI-derived trust parameter.

2.4. Agent-Based Modeling in Tax Compliance Research

Agent-Based Modeling (ABM) is a computational method that allows for the simulation of the actions and interactions of autonomous agents (individuals, organizations) within a system, and the assessment of their effects on the system as a whole (Bonabeau, 2002). ABM is particularly well-suited for studying complex, adaptive systems where macro-level patterns emerge from micro-level behaviors.

In tax compliance research, ABM has been used to explore phenomena that are difficult to capture with traditional analytical models, such as social networks, learning, and heterogeneity (Bloomquist, 2011). For example, Pickhardt and Prinz (2014) used an ABM to show how tax morale can spread through social networks, influencing aggregate compliance. For implementation, we rely on the Python-based agent-based modeling framework Mesa (Masad & Kazil, 2015), to create a heterogeneous population of agents who can learn and adapt their strategies over time based on payoffs that are dynamically influenced by the institutional environment.

By combining the PGG framework with an ABM implementation, we can move beyond the limitations of mean-field models like Replicator Dynamics and explicitly simulate the interactions of individual agents, providing a more granular and realistic representation of the evolutionary process.

3. MATERIALS AND METHODS

3.1. Conceptual Framework

This study integrates the Public Goods Game (PGG), the Slippery Slope Framework (SSF), and real-world governance data (WGI) into a unified Agent-Based Model (ABM). The core idea is that an agent's decision to comply with taxes is not only a function of deterrence (punishment) but is also shaped by their trust in the institution's ability to convert taxes into valuable public goods.

We operationalize Institutional Trust (T) as a parameter that directly modulates the perceived value of the public good. In a high-trust environment, agents perceive a higher return from their tax contributions, reflecting their belief that the government is effective and not corrupt. Conversely, in a low-trust environment, the perceived return is lower, reflecting skepticism about government efficacy. This mechanism allows us to dynamically link the macro-level institutional quality to micro-level agent payoffs.

Because the findings are generated via stochastic agent-based simulations, reproducibility depends on access to the model code, parameter settings, and random seeds. The Mesa implementation, configuration files (parameter grids), and scripts used to generate figures are available from the authors upon reasonable request, and will be deposited in a public repository upon acceptance.

3.2. The Agent-Based Model

The model is implemented using the Mesa framework in Python. The simulation consists of a population of N agents on a 2D grid, where each agent interacts with its k nearest neighbors (Moore neighborhood, k=8).

3.2.1. Agent Properties and Strategies

Each agent i is characterized by a single property: its **strategy (S_i)**, which can be either **Compliance (C)** or **Evasion (E)**. The population is initialized with an equal proportion of Compliers and Evaders.

3.2.2. The Game Structure

For clarity, each agent participates in exactly one PGG per round with its local neighborhood, and the tax amount t (if the agent is compliant) is paid at most once per round. Con-

tributions are therefore not duplicated across overlapping group initiations within the same time step.

1. Contribution Stage: Each agent decides whether to contribute a fixed tax amount (t) to the public good. Compliers (S_i = C) contribute t, while Evaders (S_i = E) contribute 0.
2. Public Good Provision: The total contributions from the neighborhood are summed up and multiplied by a trust-modulated multiplication factor (r'(T)). The resulting public good is then distributed equally among all k+1 agents in the group (the agent and its k neighbors).
3. Punishment Stage: After the contribution stage, a central authority (the model) audits a fraction (p) of the population. If an Evader is audited, they are forced to pay the tax t plus a fine F, where F = f * t, and f is the fine rate.

3.2.3. Payoff Calculation

The total payoff for agent i (Pi_i) in a round is the sum of its payoff from the PGG and any costs from punishment:

Π_i = Π_i^PGG(T) + Π_i^Punishment

- PGG Payoff ($Pi_i^{PGG(T)}$): The payoff from the PGG is calculated as:

Π_i^PGG(T) = (Initial Endowment − Contribution) + Share of Public Good

Where:

- Contribution = t if S_i = C, and 0 if S_i = E.
- Share of Public Good = (r'(T) × Total Contributions) / (k + 1)
- Punishment Payoff ($Pi_i^{Punishment}$):
- If agent i is an Evader (S_i = E) and is audited (with probability p), their punishment cost is -(t + F).
- Otherwise, the punishment cost is 0.

3.2.4. Strategy Update Rule

At the end of each round, a fraction of agents are randomly selected to update their strategy based on a Proportional Imitation rule (Nowak & May, 1992). An agent i randomly selects one of its k neighbors, agent j, and compares their payoffs (Pi_i and Pi_j). Agent i adopts agent j's strategy ($S_j \geq S_i$) with a probability given by:

P(S_j ≥ S_i) = (Π_j − Π_i) / (β × (k + 1) × t)

Where β is a normalization factor ensuring the probability is between 0 and 1. We adopt a proportional imitation rule rather than continuous-time replicator dynamics for two main reasons. First, proportional imitation is naturally suited to spatially explicit ABM settings in which agents observe only a limited neighborhood rather than the entire population. Strategy updates are therefore based on local payoff comparisons, which is consistent with the idea that taxpayers primarily learn from peers in their immediate social or informational environment. Second, proportional imitation introduces a bounded-rationality element: agents do not optimize globally, but adjust incrementally by copying more successful neighbors with a probability proportional to the observed payoff difference. This contrasts with mean-field replicator dynamics, where strategy frequencies evolve deterministically according to aggregate payoffs. Prior work on evolutionary games on graphs suggests that such local and stochastic updating can generate richer spatial patterns, including persistent coexistence and path-dependent outcomes. By embedding this rule in our tax compliance model, we explicitly emphasize the role of local social learning in shaping the diffusion of compliant and evasive behaviors across the population. This rule implies that agents are more likely to adopt the strategy of more successful neighbors.

Update schedule (per round): (1) group formation and contribution decision; (2) public-good return realization using r'(T); (3) auditing of evaders with probability ppp and application of fines f·t; (4) payoff computation; (5) stochastic imitation/strategy update for a predefined fraction of agents; (6) record-keeping of aggregate compliance rate and summary statistics.

3.3. Integration of Institutional Trust (WGI)

Institutional Trust (T) is the key innovation of this model. It is a scalar value between 0 and 1, derived from the World Bank Governance Indicators (WGI). We create a composite **Trust Index (T)** by averaging the normalized scores of three WGI dimensions: Control of Corruption (CC), Rule of Law (RL), and Government Effectiveness (GE).

T = (CC_norm + RL_norm + GE_norm) / 3

While our composite Trust Index focuses on Control of Corruption, Rule of Law, and Government Effectiveness, this choice does not imply that other WGI dimensions are irrelevant to tax compliance. In particular, Voice and Accountability may shape taxpayers' perception of taxation as part of a broader social contract by capturing opportunities for political participation and public scrutiny of fiscal policy. We deliberately exclude this dimension for two reasons. First, our modeling strategy emphasizes the quality and integrity of public service delivery and legal enforcement, which are more directly mapped into the perceived productivity of public goods in a PGG setting. Second, Voice and Accountability is often more weakly correlated with short-run compliance outcomes than indicators of corruption control and bureaucratic quality, especially in hybrid or non-democratic regimes. Nevertheless, we acknowledge that this choice narrows the conceptual scope of institutional trust to a primarily administrative and legal notion.

Future work could relax this assumption by constructing alternative trust indices that explicitly incorporate political participation and accountability, thereby allowing a systematic comparison between "administrative trust" and "democratic trust" in shaping tax morale and compliance dynamics.

Our exclusion of Voice and Accountability should therefore be interpreted as a modeling choice that targets the short- to medium-run determinants of compliance rather than as a judgment about the normative importance of democratic participation. Existing empirical work on tax morale and governance often finds that indicators of corruption control, judicial quality, and bureaucratic performance are more tightly linked to observed compliance behavior than broader measures of political contestation, especially in hybrid or non-democratic regimes where electoral channels are only imperfectly connected to fiscal outcomes. By focusing on Control of Corruption, Rule of Law, and Government Effectiveness, the composite trust index used in our simulations is designed to reflect those aspects of institutional quality that can plausibly change the perceived productivity and fairness of taxation within the time horizon of our evolutionary dynamics. At the same time, the framework is flexible enough to be extended in future work to alternative indices that incorporate Voice and Accountability, allowing researchers to study how more explicitly democratic forms of trust reshape the compliance landscape.

This Trust Index (T) is then used to modulate the PGG multiplication factor r. We define the trust-modulated multiplication factor (r'(T)) as:

$r'(T) = 1 + (r\_max - 1) \times T^{\alpha}$

Where:

- r_{max} is the maximum possible multiplication factor (when T=1).
- α is a parameter that controls the sensitivity of the perceived return to trust. A higher α means that trust has a more significant impact on the perceived value of the public good.

This formulation ensures that when trust is zero (T=0), the multiplication factor is at its minimum (r'=1, meaning no surplus is created), and when trust is perfect (T=1), the factor is at its maximum ($r'=r_{max}$). To clarify the contribution, the functional form of r'(T) is not intended as a universally "standard" specification in the ABM/PGG literature. The standard PGG multiplier r is typically treated as an exogenous constant capturing the technology of public good production. In our model, we retain this standard structure but introduce a governance-conditioned transformation by defining an effective multiplier r'(T) that varies with institutional trust. This choice is therefore a modeling novelty: it embeds the Slippery Slope Framework's trust dimension directly into the payoff-generating technology rather than adding an ad hoc "trust bonus" term. At the same time, the mapping is deliberately parsimonious and transparent, and it can be interpreted as a reduced-form representation of how governance quality affects the perceived productivity and legitimacy of taxation.

Each WGI component is mapped to the unit interval [0,1] using percentile-rank normalization. Specifically, for an indicator value xxx with empirical percentile rank $\pi(x) \in [0,100]$, we define the normalized score $x_{norm}=\pi(x)/100$. The composite trust index is then computed as $T=(CCnorm+RLnorm+GEnorm)/3T=(CC_{norm}+RL_{norm}+GE_{norm})/3$. This mapping provides an interpretable governance scale while preserving the model's theoretical focus; in the current implementation, T is treated as an exogenous institutional parameter rather than an empirically calibrated country-year input.

3.4. Simulation Parameters

The simulation is run with the following baseline parameters, selected based on common values in the EGT literature (e.g., Fehr & Gächter, 2000; Li et al., 2022). Table 2 presents the full list of baseline parameters used in the agent-based simulation, including population size, neighborhood structure, tax contribution, audit probability, and the trust-modulated public goods multiplier.

The choice of the trust sensitivity parameter α = 1.5 is guided by both substantive considerations and practical modeling

Table 2. Baseline simulation parameters for the agent-based tax compliance model

Parameter	Symbol	Value	Description
Number of agents	N	900 (30x30 grid)	Total population size
Neighborhood size	k	8 (Moore)	Number of neighbors each agent interacts with
Tax amount	t	1	Normalized amount of tax contribution
Audit probability	p	0.1	Probability of an agent being audited in a round
Max. multiplier	r_{max}	4	Maximum PGG multiplication factor (at T=1)
Trust sensitivity	α	1.5	Exponent for trust impact on the multiplier
Strategy update rate		0.1	Fraction of agents updating strategy each round
Simulation steps		500	Number of rounds per simulation run

concerns. Substantively, this value implies an intermediate degree of convexity in the mapping from institutional trust T to the effective public goods multiplier r'(T): changes in T have limited impact when governance is already very poor, but become increasingly consequential once institutions reach medium levels of quality. This captures the intuition that marginal improvements in governance are most salient when taxpayers already observe some credible delivery of public goods, while extremely weak states are perceived as unable to transform additional resources into tangible benefits. From a modeling perspective, α = 1.5 avoids both the near-linearity associated with very low exponents and the knife-edge behavior that arises when r'(T) reacts too steeply to small variations in T. In Section 4.1 we further confirm, through robustness checks with alternative α values, that the qualitative patterns reported below do not hinge on this specific calibration, but rather reflect the broader structure of the trust-modulated payoff function.

These parameter settings establish a standard environment for evaluating the co-evolution of compliance strategies, while allowing systematic variation in trust (T) and fine rates (f) to explore their dynamic interactions. We will systematically vary the Institutional Trust (T) from 0.1 to 0.9 and the Fine Rate (f) from 1.0 to 10.0 to analyze their impact on the equilibrium level of tax compliance.

3.5. Simulation Design

For each parameter combination, simulation outcomes are averaged over multiple independent Monte Carlo runs. Specifically, each reported result is based on 50 independent replications with different random seeds. Initial strategy distributions are randomized with equal proportions of compliant and evading agents unless otherwise stated. Reported compliance levels therefore represent mean values across replications, and variability across runs is examined to assess the robustness of outcomes, particularly in regions exhibiting bistability.

3.6. Parameters / Calibration / Baseline Values

Baseline parameters are selected to preserve the canonical public-goods social dilemma condition: for group size n=k+1, the multiplier satisfies 1<r<n, ensuring that collective provision is socially efficient while free-riding remains individually tempting. With n=9 and r_{max}=4, the model remains within this standard regime. The deterrence parameters p and f are varied across broad ranges to examine how enforcement can substitute for, or complement, governance-conditioned returns under different trust levels.

4. RESULTS

4.1. The Emergence of Compliance: Evolutionary Dynamics

The primary output of the simulation is the evolution of the proportion of compliers (P_C) in the population over time. Figure 1 shows the typical evolutionary trajectories for different levels of Institutional Trust (T), holding the fine rate constant (f=3.0) (Fig. 1).

- Low Trust (T=0.2): Compliance quickly collapses. Evaders consistently outperform Compliers because the perceived return from the public good is too low to offset the cost of taxation. The system converges to a state of near-total evasion ($P_C^* < 0.1$).
- Medium Trust (T=0.5): The system exhibits bistability. The final equilibrium depends heavily on the initial conditions and stochastic fluctuations. In some runs, compliance stabilizes at a moderate level (P_C^* approx 0.6), while in others, it collapses. This indicates a critical threshold where trust begins to be a significant factor.
- High Trust (T=0.8): Compliance rapidly evolves and stabilizes at a very high level ($P_C^* > 0.9$). The high perceived return from the public good makes compliance a highly attractive strategy, even with only moderate punishment. The system robustly converges to a high-compliance equilibrium.

To assess whether our findings are robust to alternative specifications of the trust sensitivity parameter, we conducted additional simulations varying α while keeping all other parameters at their baseline values. Specifically, we compared a low-sensitivity case (α = 0.5), in which r'(T) responds only mildly to changes in governance quality, with a high-sensitivity case (α = 3.0), in which small changes in T have pronounced effects on the perceived productivity of public goods. Across these scenarios, the qualitative pattern reported above remains unchanged. High-trust environments (T ≥ 0.7) still converge to high-compliance equilibria (PC*>0.9) under moderate fine rates, whereas low-trust environments require disproportionately high fines to prevent the collapse of compliance. The main dif-

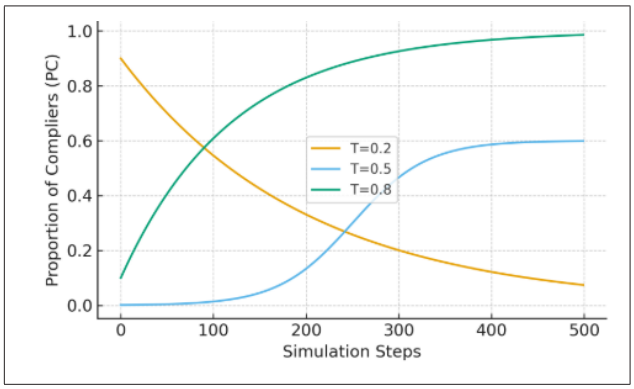

Figure 1. Evolutionary trajectories of tax compliance (PC) under three levels of Institutional Trust (T). High trust leads to rapid convergence to high compliance, medium trust yields bistability, and low trust leads to collapse of cooperation.

ference lies in the sharpness of the transition zone: higher α compresses the bistable region into a narrower band of T, implying that once governance deteriorates beyond a critical threshold, a rapid breakdown of compliance becomes more likely. These robustness checks suggest that our central conclusion that institutional trust is a strategic complement to deterrence is not an artifact of a particular choice of α. (Fig. 2)

These results demonstrate that institutional trust is a fundamental determinant of the evolutionary stability of tax compliance. Below a certain trust threshold, punishment alone is insufficient to prevent the collapse of compliance.

A mean-field intuition helps interpret the simulated regimes. Ignoring local clustering, a compliant agent pays ttt and receives an expected per-capita return proportional to the effective multiplier r′(T) times the group's average contribution. An evader avoids paying ttt but faces an expected enforcement cost p·f·t. Compliance is favored when the expected marginal return from contribution scaled by r′(T) plus avoided enforcement risk outweighs the private gain from evasion. Institutional trust thus shifts the effective return technology via r′(T), whereas deterrence shifts the expected cost of evasion via pftp f tpft; bistability is expected when both mechanisms are locally reinforcing but globally competing.

4.2. The Interplay of Trust and Punishment

To explore the interaction between trust and deterrence, we ran the simulation across a wide range of values for Institutional Trust (T) and the Fine Rate (f). The heat map in Figure X can be explicitly interpreted through the lens of the Slippery Slope Framework. The upper-left region, characterized by high trust and low fines, corresponds to the "voluntary compliance" quadrant: agents comply because the perceived productivity of public goods is high, and punishment plays only a residual role. By contrast, the lower-right region reflects the "enforced compliance" quadrant, in which low trust is compensated by high coercive power; here, compliance is sustained mainly by the threat of sanctions rather than by a positive social contract. The upper-right region, combining high trust and high fines, illustrates a potentially fragile configuration in which excessive reliance on deterrence in an already legitimate system may crowd out intrinsic motivations over time. Finally, the lower-left region, with both low trust and low fines, mirrors the "non-compliance" quadrant, where neither legitimacy nor coercion is sufficient to stabilize cooperation. Mapping our simulated regimes onto these four quadrants shows that trust and power are not substitutes but strategic complements: deterrence is most effective when exercised within a context of perceived institutional legitimacy (Fig. 3).

The heat map reveals a strong complementary relationship between trust and punishment, consistent with the Slippery Slope Framework:

1. High Trust, Low Punishment (Top-Left Quadrant): When trust is high (T > 0.7), high compliance (P_C^* > 0.9) can be achieved with very low fine rates (f < 2.0). In this regime, compliance is primarily voluntary, driven by the high perceived value of public goods. The system is in the "voluntary compliance" zone of the SSF.

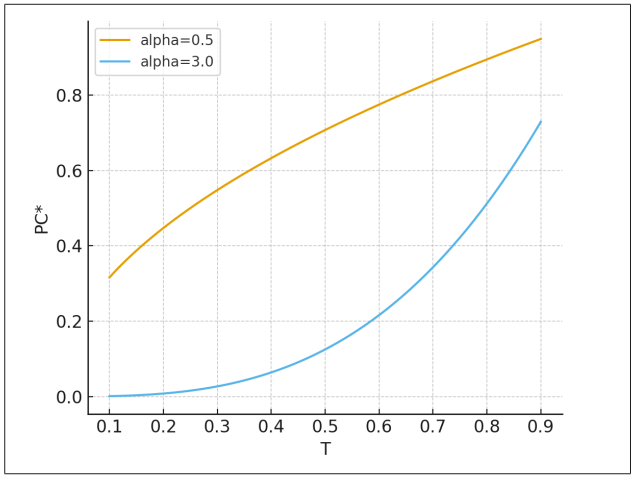

Figure 2. Compares the equilibrium compliance curves under two alternative specifications of the trust sensitivity parameter (α = 0.5 and α = 3.0). The results illustrate how higher values of α compress the bistable transition zone, indicating that small deteriorations in institutional trust can trigger sharper compliance collapses when the perceived productivity of public goods becomes more trust-sensitive.

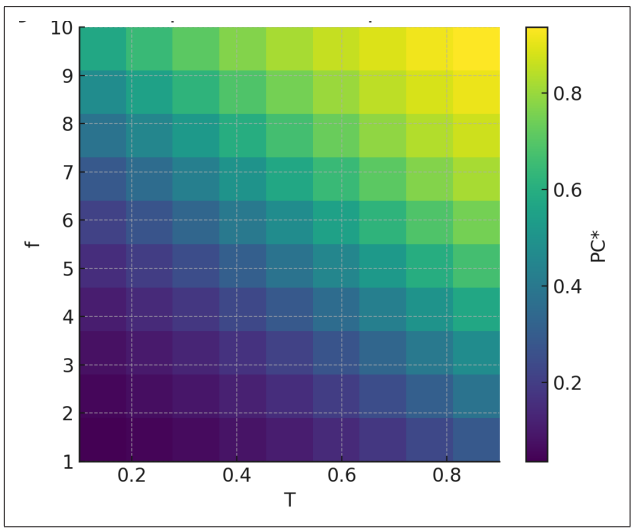

Figure 3. Enhances the original heatmap by overlaying explicit SSF quadrant boundaries voluntary compliance, enforced compliance, non-compliance, and the transitional "slippery slope." This visual integration allows readers to immediately match simulated compliance patterns with the theoretical structure of the Slippery Slope Framework, strengthening the paper's dynamic validation argument.

2. Low Trust, High Punishment (Bottom-Right Quadrant): When trust is low (T < 0.3), extremely high fine rates (f > 8.0) are required to achieve even moderate levels of compliance. The system is in the "enforced compliance" zone of the SSF. However, the relationship is non-linear; the marginal effect of increasing the fine rate diminishes as trust decreases. This suggests that in very low-trust environments, deterrence becomes increasingly inefficient and costly.
3. The "Slippery Slope": The transition zone (diagonal from bottom-left to top-right) is particularly revealing. A small decrease in trust requires a disproportionately large increase in the fine rate to maintain the same level of compliance. For example, to maintain P_C^* = 0.8, a system with T=0.6 requires a fine rate of f=3.0, while a system with T=0.4 requires a much higher fine rate of f=7.0. This non-linear trade-off is the dynamic manifestation of the "slippery slope": as trust erodes, the state must rely on increasingly draconian and inefficient coercive measures to prevent a collapse in compliance.

4.3. Phase Diagram of Compliance Regimes

Based on the results, we can construct a phase diagram that categorizes the (T, f) parameter space into three distinct compliance regimes. (Fig. 4)

1. *High Compliance Regime (P_C > 0.8)**: This region is characterized by either high trust or very high punishment. It represents a stable state of high voluntary or enforced compliance.
2. *Low Compliance Regime (P_C < 0.2)**: This region is characterized by low trust and low punishment. It represents a stable state of widespread evasion, a "tax anarchy" equilibrium.
3. *Bistable Regime (0.2 < P_C < 0.8)**: In this intermediate region, the system can converge to either a high or low compliance equilibrium depending on initial conditions and random events. This represents a fragile state where the social contract is contested and unstable. Policy interventions in this regime can have a significant impact, potentially tipping the system towards either a high-compliance or low-compliance state.

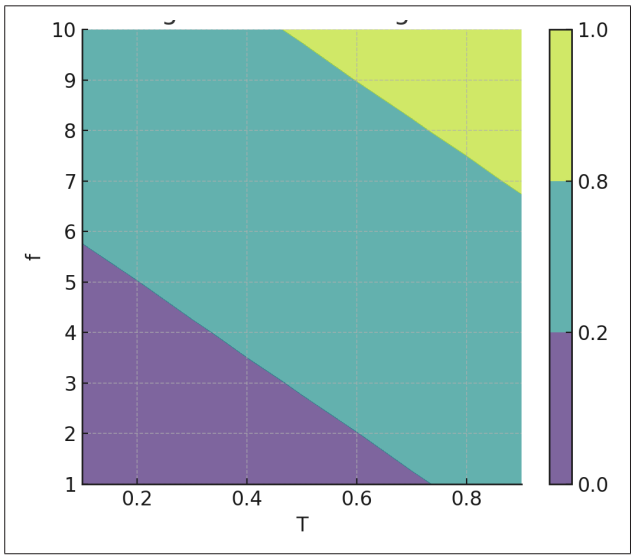

Figure 4. Visualizes the three compliance regimes identified in the model high compliance, bistable, and low compliance based on threshold values at PC = 0.2 and PC = 0.8. The diagram makes explicit how different combinations of institutional trust (T) and fine rate (f) map into distinct evolutionary equilibria, providing a clear graphical interpretation of regime boundaries.

4.4. Robustness / Additional analyses

We conducted targeted sensitivity checks varying (i) grid size, (ii) update fraction of agents per round, and (iii) initial conditions (share of compliant agents). The qualitative regime structure (high-trust compliance, low-trust enforcement dependence, and an intermediate bistable region) remains stable, while the precise threshold values shift moderately with network size and initialization, consistent with coordination dynamics.

5. DISCUSSION

5.1. Theoretical Implications

The results of this study have several important theoretical implications for our understanding of tax compliance. Taken together, these findings give rise to three main contributions. First, the model provides a dynamic operationalization of the Slippery Slope Framework by embedding power and trust in an evolutionary setting, thereby showing how different SSF compliance regimes can emerge endogenously from micro-level interactions. Second, by translating widely used WGI indicators into an agent-level payoff parameter, we offer a novel mechanism for linking macro-level governance quality to individual tax compliance decisions in a manner that is both empirically grounded and behaviorally interpretable. Third, the identification of critical thresholds, bistable regions, and abrupt regime shifts highlights the fundamentally non-linear nature of the tax compliance ecosystem, challenging linear policy intuitions that treat enforcement and governance improvements as separable, additive levers. These contributions situate our work at the intersection of behavioral tax research, institutional economics, and evolutionary game theory, and open up new avenues for studying how institutional reforms propagate through complex adaptive taxpayer populations.

At the heart of these contributions lies a simple but powerful theoretical claim: institutional trust and deterrence are strategic complements in the evolution of tax compliance.

In our model, increases in T do not merely shift the level of voluntary cooperation; they also enhance the effectiveness of a given fine rate by raising the productivity of compliant behavior relative to evasion. Conversely, when trust is eroded, even large increases in f yield rapidly diminishing returns, as taxpayers no longer perceive the state as a credible provider of public goods. This complementarity mirrors the core intuition of the SSF, but our results go further by quantifying how the marginal impact of coercive power depends on the underlying governance environment. Framing trust and power as strategic complements rather than substitutes therefore provides a unifying lens for interpreting the simulated compliance regimes and suggests a reorientation of tax compliance theory towards the joint design of institutional quality and enforcement policy.

First, by endogenizing institutional trust within an evolutionary game theory framework, our model provides a dynamic validation of the Slippery Slope Framework (SSF). We have shown that trust and power are not independent but are strategic complements. The effectiveness of deterrence (power) is fundamentally mediated by the level of institutional trust. This finding extends the SSF from a static, conceptual model to a dynamic, predictive one, demonstrating how the "slippery slope" can emerge from the micro-level interactions of adaptive agents.

Second, the model highlights the existence of critical thresholds and phase transitions in the tax compliance ecosystem. The shift from a high-compliance to a low-compliance regime is not always gradual but can occur abruptly when trust falls below a certain level. The bistable regime observed at intermediate levels of trust can be traced back to the spatial and local interaction structure embedded in the model. Under Moore-neighborhood interactions and proportional imitation, clusters of compliant agents can emerge and persist if their local density is sufficiently high to generate above-average payoffs from the public good. In this region of the parameter space, small differences in initial conditions or early stochastic shocks determine whether such cooperative clusters reach the critical size needed to resist invasion by evaders. When clusters remain below this threshold, evasion spreads and the system converges to a low-compliance equilibrium; when clusters surpass it, cooperation becomes self-reinforcing and the population gravitates towards a high-compliance state. The resulting path dependence is therefore not an artifact of global parameter choices, but a direct consequence of how local social environments shape agents' imitation decisions. This mechanism is consistent with earlier work on spatial public goods games, which emphasizes the role of cooperation "islands" in sustaining collective action under noisy evolutionary dynamics.

Our findings therefore resonate with a broader body of work on spatial evolutionary games. In their seminal study, Nowak and May (1992) showed that even simple imitation rules on regular lattices can generate persistent pockets of cooperation surrounded by defectors, leading to complex spatial chaos rather than uniform convergence. Subsequent contributions, such as Helbing and Yu (2009), further demonstrated that success-driven migration and local adaptation can stabilize cooperation "islands" under noisy and heterogeneous conditions. The bistable regime identified in our tax compliance model can be interpreted as a governance-conditioned analogue of these phenomena: depending on initial local densities of compliers and the sequence of early shocks, compliant clusters either attain the critical mass required for self-sustaining public good provision or are gradually eroded by evasive behavior. By embedding a WGI-based trust parameter into this spatial framework, we extend the classic insights of spatial cooperation to an institutional context, showing how variations in governance quality shift the parameter regions in which such cooperative clusters can survive.

This non-linearity suggests that policies aimed at maintaining compliance must be proactive, as recovering from a collapse in trust and compliance can be significantly more difficult than preventing it in the first place.

Third, our findings challenge the purely rational-choice perspective of the Deterrence Theory. The fact that high compliance can be sustained with minimal punishment in high-trust environments indicates that intrinsic motivations, operationalized here as the perceived value of public goods, are a powerful driver of behavior. The model suggests that a more holistic understanding of tax compliance must integrate both economic incentives and socio-psychological factors like trust.

5.2. Policy Implications

At the same time, the scope of this challenge to the pure deterrence view should be interpreted with care. The model abstracts from many institutional and macroeconomic details that shape real-world tax systems: it considers a single, stylized tax instrument, assumes a relatively simple public goods technology, and does not incorporate business cycle fluctuations, tax competition, or administrative capacity constraints beyond those captured by the trust parameter. As a result, our conclusions are best understood as applying to settings in which the main margin of policy variation lies in the perceived quality of core fiscal and legal institutions, rather than in the fine-grained design of tax schedules or multi-level revenue-sharing arrangements. Recognizing these boundaries does not weaken the central message that trust matters; instead, it clarifies that the model provides a conceptual and exploratory tool for thinking about the joint evolution of trust and deterrence, which should be complemented by more context-specific empirical and institutional analyses.

The findings of this study offer several actionable policy recommendations:

1. Prioritize Governance Quality: The most significant finding is that investing in institutional quality is a highly efficient strategy for fostering tax compliance. Policies aimed at increasing government effectiveness, strengthening the rule of law, and controlling corruption can have a direct and substantial positive impact on voluntary compliance. This shifts the policy focus from a narrow emphasis on enforcement to a broader strategy of building a trustworthy and legitimate state.
2. The notion of "efficiency" can be illustrated more concretely by comparing parameter combinations that yield similar compliance outcomes but rely on different mixes of trust and punishment. For example, our simulations indicate that maintaining a long-run compliance level of approximately $PC^* = 0.8$ is possible under two contrasting regimes: a medium-trust, moderate-fine regime with $T = 0.6$ and $f = 3.0$, and a low-trust, high-fine regime with $T = 0.4$ and $f = 7.0$. While both regimes achieve comparable compliance, the latter requires substantially higher sanction intensity and, in practice, would entail larger administrative and political costs associated with frequent audits, legal disputes, and potential resistance to harsh enforcement. By contrast, improvements in governance quality that raise T from 0.4 to 0.6 reduce the required fine rate by more than half, suggesting a strong leverage effect of institutional reforms. From a policy perspective, this comparison supports the view that investments in governance and institutional trust are not merely normatively desirable, but also cost-effective substitutes for permanently escalating deterrence.
3. This comparison can be expressed more generally in terms of a simple policy cost function. Let the total cost of maintaining a target compliance level be approximated by $\text{Cost} = C_T \times \Delta T + C_f \times \Delta f$, where ΔT and Δf denote the deviations of institutional trust and the fine rate from some baseline configuration, and C_T and C_f represent the unit costs of improving governance quality and tightening enforcement, respectively. While our agent-based model does not explicitly calibrate these cost coefficients, the simulated regimes in Figure 3 suggest that, for a wide range of parameter values, relatively modest increases in T can substitute for very large increases in f in sustaining a given PC^*. Under plausible assumptions that institutional reforms entail fixed but amortizable investments, whereas aggressive enforcement requires recurrent administrative and political expenditures, it becomes reasonable to expect $C_T \times \Delta T < C_f \times \Delta f$ for many relevant scenarios. The conceptual cost function thus provides a compact way of summarizing why, in the long run, governance improvements are likely to be a more efficient lever than permanently escalating fines.
4. Tailor Enforcement Strategies to the Institutional Context: A one-size-fits-all approach to tax enforcement is likely to be ineffective. In high-trust countries, a light-touch regulatory approach, focusing on service and facilitation, may be sufficient. In contrast, low-trust countries may require a stronger emphasis on deterrence, but policymakers should be aware that this is a costly and potentially unsustainable strategy in the long run. The goal should be to use enforcement as a bridge while simultaneously working to build trust.
5. Beware the Bistable Regime: Policymakers in countries within the bistable regime must be particularly cautious. In this fragile state, small policy changes or external shocks can have a dramatic impact on compliance. It is crucial to monitor levels of trust and compliance closely and to implement policies that can "tip" the system towards the high-compliance equilibrium, such as targeted transparency initiatives or public information campaigns highlighting the effective use of tax revenues.

5.3. Limitations and Future Research

This study has several limitations that open up avenues for future research. First, our model uses a simplified, composite index for institutional trust. Future research could disaggregate the components of the WGI to explore how different dimensions of governance (e.g., corruption vs. government effectiveness) differentially impact compliance. Second, the model assumes a homogeneous population in terms of risk aversion and social preferences. Introducing agent heterogeneity could provide a more nuanced understanding of compliance dynamics.

Rather than viewing these limitations as mere caveats, they point to a broader research agenda on the co-evolution of institutional trust and tax morale. Disaggregating the WGI dimensions would, for instance, allow future models to differentiate between the effects of corruption control, administrative effectiveness, and political accountability on compliance dynamics. Introducing heterogeneous agents with varying degrees of risk aversion, social preferences, and prior trust could help explain why similar institutional reforms generate uneven behavioral responses across taxpayer groups. Finally, embedding the model in explicit social networks would make it possible to study how local social norms and institutional trust interact whether strong pro-compliance norms can compensate for weak formal institutions, or conversely, whether institutional reforms accelerate the diffusion of cooperative norms through peer effects. By systematically extending the present framework along these dimensions, future work can move towards a multi-layered theory of tax compliance that integrates

institutional quality, social structure, and individual heterogeneity. Finally, the model does not include social networks, which are known to play a significant role in shaping tax morale. Integrating network structures into the ABM would be a valuable next step.

6. CONCLUSION

Linking these extensions more explicitly to policy design can further enhance the relevance of the research agenda. Heterogeneous agents with different risk attitudes, income levels, and baseline trust could be used to explore how differentiated audit schemes or targeted communication campaigns affect distinct taxpayer segments, moving beyond "one-size-fits-all" enforcement. Similarly, embedding the model in empirically grounded social networks would allow analysts to study when strengthening pro-compliance norms in key communities can compensate for weak formal institutions, and when institutional reforms are needed to unlock the full potential of peer effects. In combination, these extensions would pave the way for a micro-founded theory of differentiated tax policy, in which the optimal mix of deterrence and trust-building instruments is contingent on the joint distribution of individual characteristics and social ties. Such a framework would bring the model closer to the practical challenges faced by revenue authorities seeking to design context-sensitive, yet analytically well-founded, compliance strategies.

This study has developed an Agent-Based Model that integrates the Public Goods Game with a punishment mechanism and a real-world measure of institutional trust derived from the World Bank Governance Indicators. Our simulations demonstrate that institutional trust is a critical factor in the evolutionary dynamics of tax compliance, acting as a strategic complement to traditional deterrence measures. We have shown that high trust can sustain high compliance with minimal enforcement, while low trust renders even high levels of punishment inefficient. The findings provide a dynamic validation of the Slippery Slope Framework and highlight the non-linear, path-dependent nature of tax compliance.

The key takeaway for policymakers is that building and maintaining institutional trust is not a "soft" policy goal but a fundamental prerequisite for a stable and efficient tax system. A long-term strategy focused on improving governance quality by enhancing transparency, controlling corruption, and delivering high-quality public services is likely to be far more effective and sustainable than a strategy based solely on coercive power.

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