Measuring Structural Changes in Regional RPKI Adoption Dynamics

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***Abstract*—RPKI deployment has increased steadily in recent years, specifically since 2018. This work studies whether these ROA adoption curves can be reproduced by a bounded rational and externality adoption model. We construct quarterly ROA coverage time series from 2011 to 2025 by combining validated ROA payloads from the RIPE Historic RPKI Data Archive with BGP RIB snapshots from RouteViews. We first fit a fixed parameter logit dynamics model derived from a multiagent behavioral model. Although the model reproduces the general upward trend, it fails to capture rapid adoption changes observed around 2018 and 2019 in several regions. We then introduce a single change point in the adoption barrier parameter, which substantially improves the fit for most RIRs. The results suggest structural changes in regional RPKI deployment dynamics while also exposing limitations in interpreting aggregate adoption curves as direct evidence of AS-level behavior.**

***Index Terms*—RPKI, BGP, Routing Security, Adoption Dynamics, Bounded Rationality**

I. Introduction

BGP provides reachability across the Internet by allowing Autonomous Systems (ASes) to advertise IP prefixes and propagate routes learned from neighboring ASes. However, BGP does not by itself verify whether the origin AS of a route owns the corresponding prefix. As a result, accidental route leaks and intentional prefix hijacks have occurred [2].

Resource Public Key Infrastructure (RPKI) addresses this problem by enabling validation of route origins [3]. In RPKI, ASes owning prefixes publish Route Origin Authorizations (ROAs), and ASes receiving the route announcement can perform Route Origin Validation (ROV). The security benefit of ROA deployment increases when more networks perform ROV, while the operational benefit of ROV increases when more prefixes are covered by ROAs. This interdependence creates a coordination problem and has been discussed as one reason for slow RPKI deployment [4], [5].

Despite this problem, RPKI deployment has increased in recent years. Prior measurement studies have documented the growth of RPKI deployment and the difficulty of observing ROV directly from public data [6], [7].

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Prior work proposed that bounded rationality and externalities may contribute to this spontaneous RPKI deployment growth through a multi-agent adoption process [8]. However, it remains unclear whether such behavioral assumptions are consistent with observed longitudinal deployment data.

This work addresses the following research question: can a bounded-rational multi-agent adoption model reproduce the regional ROA coverage trajectories observed from 2011 to 2025? Directly fitting the full multi-agent model to each RIR time series is computationally prohibitive, so we employ logit dynamics as a surrogate model that approximates the aggregate adoption trajectory induced by the bounded-rational agent population. We fit the surrogate to each RIR time series and map the fitted parameters back to the underlying multi-agent behavioral parameters.

This work makes three contributions: (i) we construct longitudinal RIR-level ROA coverage time series from public RPKI and BGP data; (ii) we show that fixed-parameter bounded-rational adoption dynamics fail to reproduce observed deployment trajectories; and (iii) we demonstrate that a single structural change in the adoption barrier substantially improves the fit and identify an interpretability gap in the surrogate-to-multi-agent parameter mapping[1]

II. Background and Measurement Data

A. BGP, RPKI, ROA, and ROV

In BGP, an AS advertises the prefixes it originates, and other ASes propagate selected routes according to their local routing policies. Since ordinary BGP route selection does not validate origin authorization, a route with an unauthorized origin AS may still be accepted and propagated.

RPKI reduces this risk by allowing a prefix holder to publish a ROA that binds an IP prefix to an authorized origin AS [3]. A network that receives a BGP announcement can then perform ROV and classify the route as valid, invalid, or not found. ROA publication and ROV deployment are voluntary

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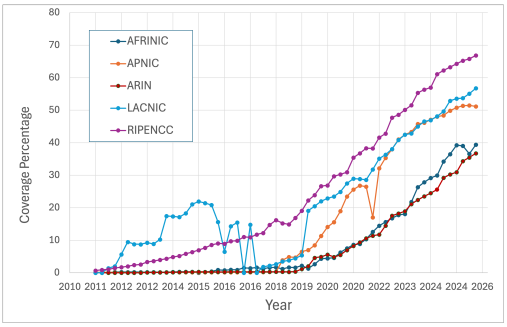

Fig. 1. Regional Coverage Time Series

operational decisions. Therefore, adoption depends not only on technical feasibility but also on deployment cost, perceived risk, operational practice, and expected external benefit [4], [9].

B. Measurement Data

We construct quarterly ROA coverage time series from 2011 to 2025. We define ROA coverage as the fraction of BGP-visible prefix-origin pairs for which a valid ROA exists. For each quarter, we obtain validated ROA payloads from the RIPE Historic RPKI Data Archive [10] and BGP Routing Information Base snapshots from the RouteViews Archive [11]. We then compare BGP visible route announcements with the available validated ROA payloads and compute the fraction of announced routes covered by ROAs. The resulting metric is an aggregate ROA coverage measure for BGP visible routes, grouped by RIR.

Figure 1 shows the resulting regional time series. The trajectories exhibit clear regional heterogeneity. AFRINIC, APNIC, and ARIN show low coverage for a long period followed by sharper increases. RIPE NCC shows a more gradual and sustained increase. LACNIC is difficult to interpret because its coverage includes an abrupt decrease followed by recovery. Such a pattern is unlikely to reflect ordinary deployment decisions alone, so we treat LACNIC as a cautionary case rather than as a primary basis for general conclusions.

III. Modeling and Results

A. Fixed Parameter Adoption Model

Our starting point is a bounded rational multi-agent adoption model [8]. In the full model, each AS decides whether to adopt ROA or ROV by comparing expected benefit and operational cost. The benefit depends on the amount of traffic that becomes protected through the combined deployment of ROA and ROV. The cost represents operational burden, configuration risk, and related deployment overhead. Here let $BV_t(i)$ and $CV_t(i)$ ($BA_t(i)$ and $CA_t(i)$) be the benefit and cost of ROV (ROA) adoption (See [8] for the detailed calculations). Then, ROV adoption is modeled probabilistically rather than as a deterministic threshold decision, so that the model can represent bounded rational behavior as Eqn. (1).

$$\Pr\left[\text{AS } i \text{ adopt ROV at time } t\right] = \frac{1}{1+\exp\left(-\lambda \frac{BV_t(i)-CV_t(i)}{CV_t(i)}\right)}, \tag{1}$$

In addition, externalities where ASes takes into account the benefit of their descendant ASes are modeled as Eq. (2).

$$BV_t^{da}(i) = BV_t(i) + \mu \sum_{k:k \text{ is descendant of } i} BV_t(i,k), \tag{2}$$

(In both cases, ROA adoption is modeled analogously).

Directly fitting the full multi-agent model to each RIR time series is computationally expensive. We therefore use a surrogate model based on logit dynamics [12] as Eqn. (3), which models only the aggregate coverage ratio, treating individual AS-level dynamics as implicit.

$$\frac{\mathrm{d}x}{\mathrm{d}t} = \frac{1-x}{1+\exp(-(\delta x - c))} \tag{3}$$

The surrogate model describes the evolution of the aggregate adoption fraction using two parameters: an externality parameter, which controls how strongly adoption becomes more attractive as coverage increases, and an adoption barrier parameter, which represents the effective difficulty of deployment.

We first fit the logit dynamics model with fixed parameters over the entire observation period. The model captures the broad upward trend in ROA coverage, but it does not reproduce the timing and shape of the observed increases. In particular, the fixed model fails to capture rapid changes around 2018 and 2019 in several RIRs (Fig. 2). This result indicates that a single stationary adoption environment is not sufficient to explain the observed regional trajectories.

B. Time Varying Adoption Barrier

We next allow the adoption barrier parameter to change once during the observation period. This single change point model remains simple, but it can represent a structural shift in deployment conditions. For example, the effective adoption barrier may decrease when operational tools improve, when RIR support becomes stronger, or when operators perceive routing security risk more clearly (Fig. 3). These interpretations are consistent with prior work reporting operational and institutional barriers to RPKI adoption [4], [9].

The time varying model substantially improves the fit for most regions. In our current results, AFRINIC, APNIC, and ARIN have estimated change points around 2018 and 2019. LACNIC also yields a change point around 2019, but this result should be interpreted cautiously because of its irregular coverage drops. RIPE NCC shows a later fitted change point, suggesting either a different regional adoption dynamic or a limitation of the one change point surrogate model.

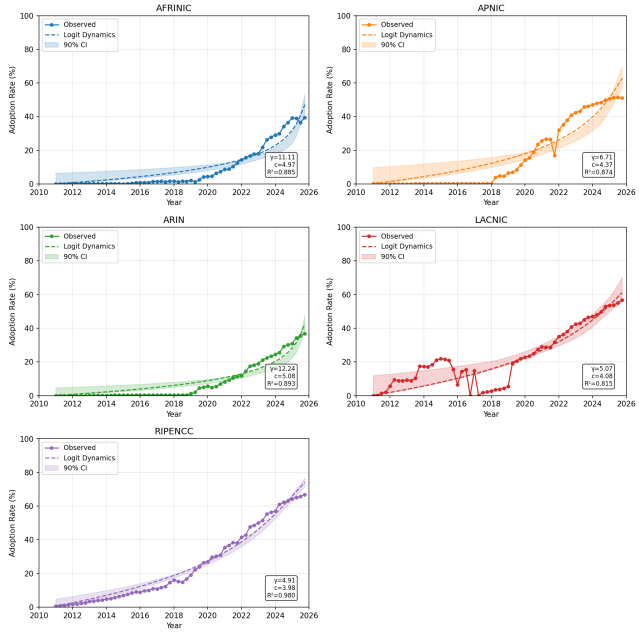

Fig. 2. Fitting Result for Fixed Parameter Model

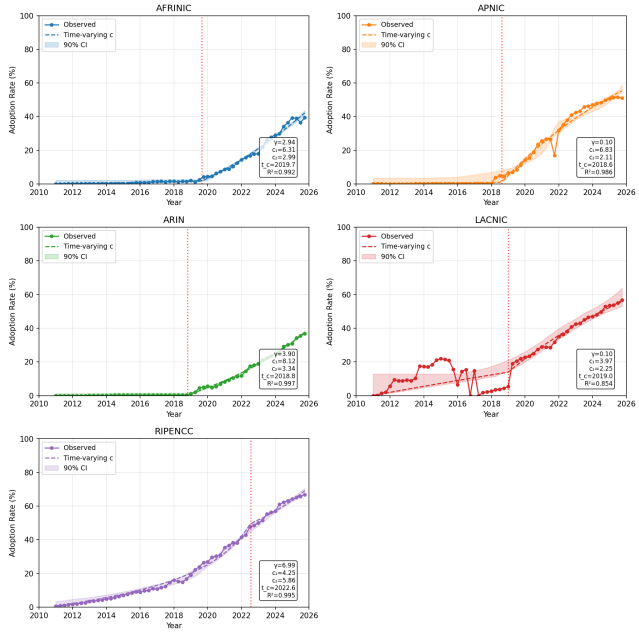

Fig. 3. Fitting Result for Time-varying Parameter Model

C. Mapping Back to the multi-agent Model

Finally, we examine whether the fitted surrogate dynamics can be reproduced by the bounded rational multi-agent model. We perform parameter sweeps over the multi-agent model and construct an approximate inverse mapping from surrogate parameters to behavioral parameters. We then infer multi-agent parameters corresponding to the fitted surrogate model and rerun the simulations.

The simulations broadly reproduce the observed regional

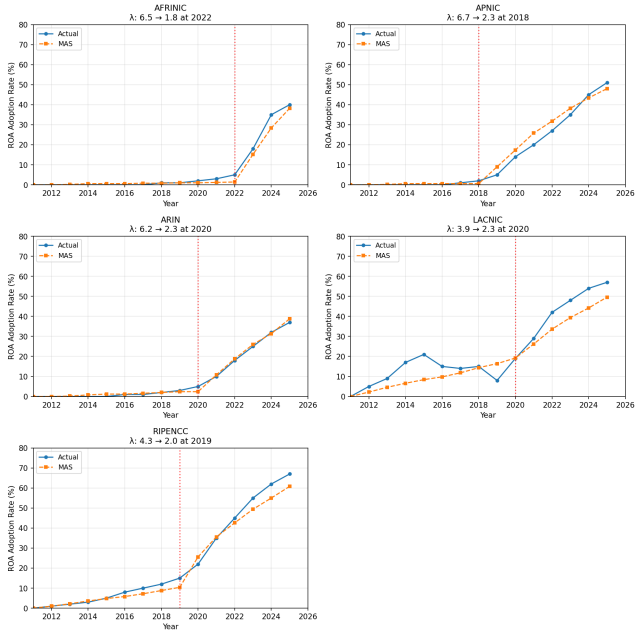

Fig. 4. Fitting Results with Time-Varying Multi-agent Model

adoption trajectories (Fig. 4). This suggests that the behavioral model can generate adoption curves similar to the measured data when its parameters are allowed to vary over time. However, the mapping also reveals an interpretability issue. In the surrogate model, the time varying parameter is the adoption barrier, which has a natural operational interpretation. In the multi-agent remapping, the same aggregate dynamics can alternatively be represented as changes in the effective bounded-rational response parameter λ. This is harder to interpret directly, because events around 2018 and 2019 are more naturally associated with perceived risk, operator incentives, or deployment cost than with a direct change in rationality.

IV. Conclusion and Future Works

In this paper, we investigated whether a bounded-rational adoption model with externalities can reproduce observed regional RPKI deployment trajectories. Although the fixed parameter model fails to capture rapid adoption changes observed around 2018 and 2019 in several regions, introducing a single change point in the adoption barrier parameter substantially improves the fit for most RIRs, with inferred change points coinciding across regions around 2018–2019.

Two limitations deserve attention. First, the dependent variable is aggregate ROA coverage observed from public RPKI and BGP data, not a direct measurement of individual AS decisions, and the analysis can be affected by RPKI repository changes, BGP visibility, and RIR-specific operational practices. Second, the surrogate-to-multi-agent remapping reveals an interpretability gap: the structural change inferred as a shift in the adoption barrier maps onto a change in the bounded-rationality parameter λ in the multi-agent model, which is harder to reconcile with the operational events of 2018–2019.

Resolving this gap and moving from aggregate fitting to AS-level prediction, where we incorporate AS attributes, customer-provider structure, and historical deployment behavior, are priorities for future work. A complementary direction is to evaluate whether alternative behavioral models, such as adjacency-based adoption effects, can equally reproduce the observed regional trajectories, and to assess the conditions under which the bounded-rationality assumption is identifiable from aggregate data.

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