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Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 48(0)

Authors
Lin, Kaiying
Watty, Jens N.
Watty, Deborah
et al.

Publication Date
2026

Voice Preferences Across Yami, Atayal and Paiwan Languages: A Hierarchical Bayesian Analysis

Kaiying Lin (limkhaiin@as.edu.tw)[1], Jens N. Watty[1], Deborah Watty[1], Patrick O'Neil[1] & Joshua K. Hartshorne[2]

[1]Institute of Linguistics, Academia Sinica

[2]Department of Communication Sciences and Disorders, MGH Institute of Health Professions

Abstract

Philippine-type Austronesian languages are well known for their rich voice systems, which include up to four voices that differ in which argument is the subject, rather than a simple active-passive contrast. These languages present a challenge to language acquisition theories, because they lack the robust relationship between causal agents and sentential subjects, a foundational assumption of both Nativist and Empiricist theories. We focus on one key issue: verbs differ in the voices they allow or prefer, raising questions about how children may acquire these patterns. We examine voice–semantics associations in three Austronesian languages spoken in Taiwan: Atayal, Paiwan, and Yami, using hierarchical Bayesian modeling to estimate probabilistic voice preferences for individual verbs while accounting for data sparsity. Hierarchical clustering of posterior distributions reveals overall biases in voice usage and partial alignment between semantic themes and voice-marking patterns, suggesting that voice-semantics distributions are systematic in ways learners may exploit during acquisition.

Keywords: Austronesian languages; Voice marking; Semantics; Bayesian Hierarchical modeling; Hierarchical clustering; Taiwan

Introduction

Theorists from many traditions posit a tight relationship between causal agents and syntactic subjects. Nativist theories of language acquisition such as Semantic Bootstrapping and Syntactic Bootstrapping depend on an unlearned relationship between agent and subject to get learning off the ground (Fisher et al., 2010; Gleitman, 1990; Pinker, 1984), while many Empiricist theories assert that syntactic subjects are widespread across languages precisely because they serve to express causal agency (Cristofaro, 2009; Slobin, 1985; MacWhinney, 1977; Mithun, 1991).

This perspective is challenged by Philippine-type languages, a subset of the Austronesian language family, where the link between subject and agent is more tenuous if it exists at all. Austronesian languages constitute one of the world's largest and most geographically widespread language families, including languages spoken in Taiwan, Southeast Asia, the Pacific Islands, and Madagascar (Adelaar & Himmelmann, 2004; Blust, 2013; Li et al., 2024). The family is characterized by considerable typological diversity, particularly in phonological systems, morphological complexity, and patterns of argument realization. One of the most prominent and widely discussed features of many Austronesian languages, particularly those spoken in Taiwan and the Philippines, is their rich verbal voice system. In these languages, verbal morphology indicates the most salient noun and its function in the sentence, such as actor, patient, instrument, or location. Example (1) illustrates four voices in Yami, in which the actor (1a, the noun who initiates an action), patient (1b, the noun which receives the action), instrument (1c), or location (1d) are marked with the nominative case, respectively.[1]

(1) Yami

Abbreviations: *S = Singular, 3 = 3rd Person, NOM = Nominative Case, OBL = Oblique Case, GEN = Genitive Case, AV = Actor Voice, PV = Patient Voice, IV = Instrumental Voice, LV = Locative Voice*

a. Actor Voice (subject: Salang; Rau & Dong, 2006)

k<om>an	so	wakay	si
<AV>eat	*OBL*	*sweet.potato*	*NOM*
Salang.			
Salang			

'Salang wants to eat a sweet potato.'

b. Patient Voice (subject: sweet potato; Rau & Dong, 2006)

kan-en	na	ni	Salang	o
eat-PV	*3.S.GEN*	*GEN*	*Salang*	*NOM*
wakay.				
sweet.potato				

'The sweet potato was eaten by Salang.'

c. Instrument Voice (subject: knife; Her & Deng, 2012)

ya	ko	ya-kan	so	among	o
Aux	*I.GEN*	*IV-eat*	*OBL*	*fish*	*NOM*
ipangan		ya.			
knife		*Aux*			

'I eat fish with the knife.'

[1] Note that this argument has been analyzed in different ways and described as either the "subject" or "pivot" (Chen & McDonnell, 2019). We use "subject" and "nominative" descriptively, not as theoretical claims.

d. Locative Voice (subject: seashore; Her & Deng, 2012)

ya	ko	pi-akan-an	so	among	o
Aux	*I.GEN*	*eat-LV*	*OBL*	*fish*	*NOM*
pasalan	ya.				
shore	*Aux*				

'This seashore is where I eat fish.'

The reason this pattern challenges acquisition theory is not that there are multiple voices. Notably, many languages have a passive voice, in which the causal agent (if there is one) is not the subject (e.g., *The vase was broken by the cat*). However, passive sentences are relatively rare and involve marked morphology, presumably allowing learners to disregard these sentences or treat them as atypical. In many Philippine-type languages, however, all four voices involve overt morphology, and often Actor Voice, where the agent is the subject, is not the most common.

One possibility is that the voice pattern is learned in an entirely bottom-up fashion, based on the input (Garcia & Kidd, 2020). This, however, raises a different problem, which is the focus of our study: while some verbs are attested in all four voices, some studies have suggested restrictions, with specific verbs dispreferring or not allowing certain voices (Chang, 2006; Rau & Dong, 2016). This presents a standard learning challenge: How would children learn which verbs allow which voices (see, for instance, Pinker, 1989)?

Another possibility is that children rely on a correlation between the verb's meaning and its syntactic behavior: verbs with similar meanings behave in similar ways (this is a gross simplification; for details, see Perfors et al., 2010; Pinker, 1989). Indeed, some authors have hinted at such correlations in the voice system. For example, Rau and Dong (2016) documented that the Patient Voice in Yami tends to co-occur with telic verbs whose events involve a clear endpoint, while Chang (2006) reported that the Actor Voice in Paiwan is associated with gesture and positional verbs. However, existing studies are largely based on qualitative analyses or limited sets of examples, and have not been evaluated using larger-scale quantitative data. As a result, it remains unclear how robust these voice–semantic associations are across the broader verbal lexicon, whether they reflect general distributional tendencies rather than properties of a restricted subset of verbs, and how these patterns (if any) vary across languages.

In this study, we examined the voice–semantics relationship using a hierarchical Bayesian model, which estimates the probabilistic distribution of voice marking for individual verbs while accounting for data sparsity across the lexicon. We then applied a hierarchical clustering approach to group posteriors into clusters, and analyzed the respective semantic themes in each cluster. We found some correlations between the semantics and voice distribution, but perhaps more data should be included to show more robust correlations. Therefore, we conclude that the input may contain sufficient information for children to acquire voice preferences and distributions by leveraging correlations between semantics and voice marking, for instance through mechanisms such as Semantic Bootstrapping (Pinker, 1989), though future research is needed to test this directly.

Note that this paper is a computational study of the learning problem, not a direct study of acquisition. To date, there have been only a handful of studies of voice acquisition (Garcia et al., 2018; Garcia & Kidd, 2020; Lin et al., 2022), primarily focusing on children's preferences for word order strategies, such as placing agents or patients earlier in the sentence. While important first steps, they do not directly address how learners acquire knowledge of voice-marking distributions themselves, and thus provide minimal constraint on the problem studied here.

Austronesian Languages in Taiwan

The Austronesian languages of Taiwan are spoken by indigenous peoples across different regions of the island, including mountainous inland areas and offshore islands. There are 16 officially recognized indigenous languages, with speaker populations ranging from a few hundred to several tens of thousands. Atayal is spoken mainly in the northern and central mountainous regions of Taiwan, while Paiwan is spoken primarily in the southern part of the island (see Figure 1). Yami (also known as Tao) is spoken on Orchid Island (Lanyu), located off the southeastern coast of Taiwan. Unlike most indigenous languages spoken on the main island, Yami is commonly classified as a Malayo-Polynesian Austronesian language rather than a Formosan language. This classification is motivated by its close linguistic similarities to Batanic languages spoken in the northern Philippines, reflecting historical migration and contact (Blust, 2019). As with many indigenous languages in Taiwan, all three languages face varying degrees of endangerment, and most of the available linguistic data comes from fieldwork documenting adult speech as well as (few) official documents in the languages. The lack of available child-directed speech data in these languages makes the investigation of child language acquisition difficult, motivating the use of computational modeling to approximate the linguistic input to which children may be exposed.

Method

To explore the relationship between verb semantics and voice patterns, we analyzed verbs found in annotated corpora of Atayal, Paiwan, and Yami and applied Bayesian hierarchical modeling to estimate probabilistic voice frequencies, accounting for sparse observations in the corpus. We performed hierarchical clustering on the posterior mean vectors, assessing whether verbs with similar semantics tend to share similar distributions of voice usage.

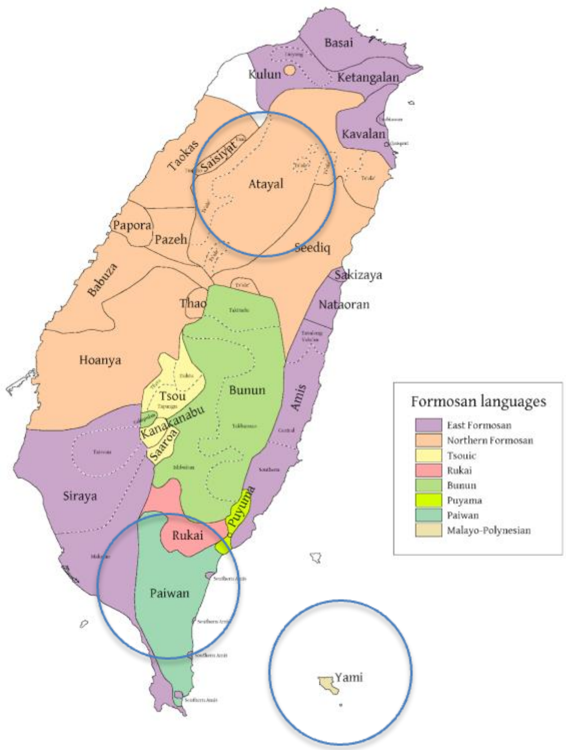

Figure 1: Traditional distribution of Austronesian languages in Taiwan. Circles indicate the languages we examined in this study (Figure adapted from Li (2010), which was developed from his many earlier studies).

Data

The data analyzed in this study come from three Austronesian languages spoken in Taiwan: Atayal, Paiwan, and Yami. The Atayal data were extracted from the NTU Indigenous Languages Corpus (Su et al, 2008; Sung et al, 2008), which contains transcribed and morphologically annotated stories. The Paiwan and Yami data were drawn from FormosanBank (Hartshorne et al., 2024), a curated database of Formosan language materials such as published academic literature and fieldwork data. The Paiwan data is a collection of 100 folktales and narratives about traditional practices, as well as Christian sermons and prayers (Early & Whitehorn, 2003). The Yami data consists of narrative and conversational texts documented in previous descriptive work (Rau & Dong, 2006).

Data Preprocessing

For all three languages, verb tokens were manually grouped by verb stem. Morphological variants such as reduplication or allomorphy were treated as belonging to the same verb if they did not substantially alter the core lexical meaning. In contrast, compounds or derivations involving affixes, notably causative markers, that clearly changed the verb's semantics were treated as separate lexical items. Verbs and voices were identified based on the available morphological annotations: "verbs" were those words with glossed voice affixes. There are several imprecisions that should be noted: We identified instances where the same form was inconsistently annotated across occurrences, for example with differing or missing voice labels. In some cases, the same word appears to have been spelled differently (most Formosan languages have a number of orthographic standards, which can complicate matters for an individual transcriber). In such cases, we did our best to standardize, though the size of the dataset means errors likely still remain. Moreover, the notion of "verb" is cross-linguistically complex, and it may be that some voice-marked forms are better analyzed as nouns or adjectives; we included them in the data for having voice marking. After this process, the final dataset consisted of 412 Yami, 193 Atayal, and 647 Paiwan verb stems for modeling.

Bayesian Hierarchical Modeling

We employed Bayesian inference for the present study because it allows us to model probabilistic preferences while accounting for data sparsity and noise in the data. Unlike raw frequency-based analyses, Bayesian hierarchical models distinguish between the absence of a form due to limited observations and the absence due to genuine distributional tendencies, by pooling information across verbs with different frequencies. This is especially important in the study of under-documented languages, where corpora are necessarily small and uneven. The model also provides full posterior distributions over voice preferences, enabling graded interpretations rather than categorical judgments, and yielding inferences that can be further manipulated and examined.

For each verb, observed voice counts were modeled as drawn from a multinomial probability distribution over the four voices, $\boldsymbol{y}_\mathrm{i} \sim \mathrm{Mult}(\boldsymbol{\theta}_\mathrm{i})$. These verb-specific parameters were assumed to be drawn from a shared Dirichlet prior, allowing information to be pooled across verbs, $\boldsymbol{\theta}_\mathrm{i} \sim \mathrm{Dir}(\alpha \cdot \boldsymbol{\mu})$, where α was drawn from a log-normal prior, $\log(\alpha) \sim \mathrm{Normal}(0, 1)$ and $\boldsymbol{\mu}$ was drawn from a uniform Dirichlet prior, $\boldsymbol{\mu} \sim \mathrm{Dir}(1, 1, 1, 1)$.

The model was implemented in PyMC (Abril-Pla et al., 2023) and fitted using the No-U-Turn Sampler (NUTS). For each language, we ran seven chains with 2,000 tuning steps and 10,000 posterior samples per chain, using a target acceptance rate of 0.95 and a maximum tree depth of 10. Convergence was assessed using standard diagnostics, including the potential scale reduction statistic ($\hat{R}$) and effective sample sizes (ESS).

All models showed good convergence (all $\hat{R} = 1.00$), with no divergent transitions and high effective sample sizes (bulk and tail ESS exceeded 1000 for all parameters), indicating good mixing and reliable posterior inference. Posterior means of verb-specific voice distributions were extracted for subsequent analysis.

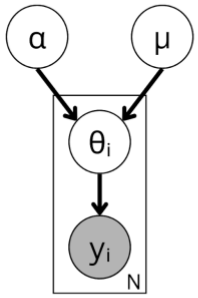

Figure 2: Graphical representation of the hierarchical Dirichlet model.

Hierarchical Clustering

To explore whether verbs group together based on similar voice preferences, we performed hierarchical clustering (Virtanen et al., 2020) on the posterior distributions. Clustering was restricted to verbs with at least four occurrences in the corpus to reduce noise from extremely sparse items. Distances between distributions were computed using Jensen–Shannon distance and the "average" linkage method was used, in which the distance between clusters is defined as the average distance between all pairs of items across clusters. We selected the dendrogram cut height according to a combination of two criteria: (i) the width of the linkage-distance interval over which the cluster count remains constant, and (ii) the silhouette score of the resulting clustering. Under these criteria, the four-cluster solution consistently ranked among the top candidates across all three languages and was not outperformed by any alternative solution on both criteria simultaneously.

Clusters were then examined in terms of their average voice distributions, dominant voice (i.e., the most probable voice per verb), and entropy. Lastly, we manually examined the most dominant semantics in each cluster.

Results

Table 1 shows posterior values for the model parameters. Values for μ reflect the estimated probability that a previously unobserved verb appears in each of the four voices. For all three languages, Actor Voice (AV) is numerically most likely, followed by Patient Voice (PV), Locative Voice (LV), and Instrument Voice (IV), in that order, though this was less pronounced for Paiwan (33% AV) than for Atayal and Yami (48% and 45%, respectively). Note that while this means the typical verb will be biased towards AV, individual verbs may not be. The value of α controls how skewed individual verbs are estimated to be toward a single voice, with smaller values indicating increasingly greater skew. The marginal distribution of $\boldsymbol{\theta_{ik}}$ is

$$\theta_{ik} \sim \mathrm{Beta}(\alpha\mu_k, \alpha - \alpha\mu_k).$$

Since our posterior estimates for the first shape parameter $\boldsymbol{\alpha} \cdot \boldsymbol{\mu_k} < \mathbf{1}$ for all k for all languages, the marginal probability density of $\boldsymbol{\theta_{ik}}$ diverges to infinity at 0. Since the same is true for the second shape parameter, $\boldsymbol{\alpha} - \boldsymbol{\alpha\mu_k}$, for most k across languages (for some voices, values above 1 are within our uncertainty estimate), the marginal probability density also diverges at 1. Therefore, while the posterior distributions for each language have a mean specified by $\boldsymbol{\mu}$, most verbs are expected to favor one of the four voices over the others. This is also reflected in the mean entropy of the posterior distributions of all verbs, which is close to 1 bit for all three languages (while it could maximally reach 2 bits if all voices were equally likely for all verbs).

The global preference for AV is further confirmed by Table 2, which presents the percentage of verbs which are predicted to occur most often in the respective voice based on the posterior estimate. We see that AV is preferred by most verbs, followed by PV. This is interesting given that, based on some qualitative analyses, PV is reported to be the most common voice in some Austronesian languages (Cooreman et al., 1984; Sauppe et al., 2013).

Table 1: Posterior means (± SD) of global Dirichlet parameters.

Language	$\boldsymbol{\alpha}$	$\boldsymbol{\mu[AV]}$	$\boldsymbol{\mu[PV]}$	$\boldsymbol{\mu[IV]}$	$\boldsymbol{\mu[LV]}$
Atayal	1.00 ± 0.16	0.48 ± 0.03	0.25 ± 0.03	0.07 ± 0.01	0.20 ± 0.02
Paiwan	1.08 ± 0.11	0.33 ± 0.02	0.28 ± 0.02	0.18 ± 0.01	0.20 ± 0.01
Yami	1.15 ± 0.14	0.45 ± 0.02	0.26 ± 0.02	0.12 ± 0.01	0.17 ± 0.02

Table 2: Distribution of verbs by primary voice preference (based on posterior estimates).

Percentage of verbs	AV	PV	IV	LV
Atayal	60%	27%	3%	10%
Paiwan	57%	19%	7%	16%
Yami	51%	26%	13%	10%

Cluster results for Yami, Atayal, and Paiwan are shown in Tables 3–5, respectively. For all three languages, cluster analyses showed four distinct clusters, of which one cluster is biased towards AV, one towards PV, one to IV, and one to LV. Notably, for all three languages, the PV cluster is less monopolar: verbs in this cluster are also biased towards AV, albeit less strongly.

Consistent with the ergative analysis of Philippine-type languages (Aldridge, 2004), the single argument of semantically intransitive verbs (e.g., *run*, *come*) typically bears the same case marking as the patient of classically transitive verbs (e.g., *eat*, *bite*). However, this is a statistical tendency: PV-biased verbs in particular frequently appear in AV.

Were there semantic patterns? Indeed, in all languages, the AV cluster was dominated by semantics which are typically associated with intransitive verbs, while the PV cluster was dominated by transitive verbs. The other two clusters were less consistently defined. The IV cluster contained many emotion verbs for Yami but had no clear theme in Paiwan and consisted of two non-emotion verbs in Atayal. The LV cluster admitted no obvious semantic theme in Yami but contained a disproportionate (though not overwhelming) number of transfer verbs in Atayal and Paiwan.

Table 3: Clustering results for Yami.

Cluster	Dominant voice	#Verbs	Theme	Examples	Average Posterior Mean			
					%AV	%PV	%IV	%LV
1	Actor Voice	34	Intransitive verbs	*'run', 'speak', 'swim', 'catch-fish', 'go', 'return', 'be-at', 'go-to-school', 'come'*	80	5	8	8
2	Patient Voice	31	Transitive verbs	*'chase', 'eat', 'listen', 'look-for', 'do', 'see', 'kill'*	30	58	5	7
3	Instrument Voice	11	Emotional verbs	*'miss', 'angry', 'worry', 'hurt', 'give'*	13	8	66	13
4	Locative Voice	8	Not obvious	*'imitate', 'enter', 'know', 'touch'*	20	9	3	67

Table 4: Clustering results for Atayal.

Cluster	Dominant Voice	#Verbs	Theme	Examples	Average Posterior Mean			
					%AV	%PV	%IV	%LV
1	Actor Voice	31	Intransitive verbs	*'sleep', 'speak', 'stay', 'talk', 'walk', 'go$_1$', 'come', 'come-from'*	77	6	2	14
2	Patient Voice	23	Transitive verbs	*'know', 'eat', 'prepare', 'live', 'bring', 'shoot'*	26	64	4	7
3	Instrument Voice	2	Not enough data to ascertain	*'carry', 'cause-decide'*	25	18	47	10
4	Locative Voice	6	Verbs involving transfer?	*'teach', 'go$_2$', 'give'*	14	9	6	71

Table 5: Clustering results for Paiwan

Cluster	Dominant voice	#Verbs	Theme	Examples	Average Posterior Mean			
					%AV	%PV	%IV	%LV
1	Actor Voice	64	Intransitive verbs	*'arrive', 'cause-come', 'die', 'go', 'stand', 'sit', 'meet', 'return', 'swim', 'know'*	78	8	5	10
2	Patient Voice	40	Transitive verbs	*'burn', 'bite', 'cause-eat', 'do-what' 'eat', 'fight', 'follow'*	30	57	7	8
3	Instrument Voice	8	Not obvious	*'discard', 'cause-put-prepare'*	5	4	83	8
4	Locative Voice	22	Verbs involving transfer?	*'leave', 'cause-see', 'ask', 'cause-give'*	9	17	13	62

Discussion

Our analyses admit three major conclusions. First, in all three languages there was a slight preference for AV. This was unexpected and appears to distinguish these languages from Tagalog (Garcia et al., 2018; Galang, 1982) in which PV seems the most canonical and acquired the earliest. AV represents a relative majority in our results, confirming these languages' status as a problem for many mainstream acquisition theories.

Second, rather than verbs appearing freely in all four voices, most are strongly biased towards a single voice. Moreover, there are distinct groups of verbs that are biased towards each of the four voices. Without judgment studies, it is difficult to say whether any verbs forbid one or more voices, particularly since our corpora are small and unattested forms are expected.

Third, there do appear to be correlations between the meaning of a verb and its voice preferences. This was clearest for the AV- and PV-biased clusters. The other two clusters had less obvious patterns that may vary across languages.

Even for AV- and PV-biased clusters, there are verbs which are not consistent with the theme in the cluster. For example, prototypically transitive verbs such as *know* appear in the AV cluster in Paiwan, while an intransitive meaning *live* exists in the PV cluster in Atayal. There are a number of possible explanations, which we cannot tease apart at this time. These exceptions may simply reflect a high degree of uncertainty in our analyses: most verbs have only a handful of observations and thus a certain number of misclassifications are expected. Alternatively, these may reflect nuances in meaning that are not clear to us and which will require careful elucidation with the help of native-speaking experts. Another possibility is that we have misidentified the semantic themes; partly because we do not have many examples of each cluster, and partly because, with only four clusters, there may be a many-to-one mapping from semantics to verb cluster (multiple semantically-defined groups of verbs appear in the same cluster).

We began this paper by asking how children could learn the voice systems of Philippine-type languages, given that these lack a close association between agents and subjects, something assumed by many theories. We noted that this becomes particularly difficult if verbs have strong, *unpredictable* biases towards certain voices.

While there are clear (production) biases, these do not appear to be entirely unpredictable. One possibility is that this reflects what people talk about: *swim* is usually used in AV because it is often used with a single argument, who happens to be the actor. If so, this is not really a language acquisition problem, any more than the fact that people rarely talk about *blue apples* is an arbitrary fact about collocations.

However, many verbs, such as the Yami equivalent of *eat*, can seem at least theoretically consistent with multiple voices, and there is no immediately obvious *a priori* reason to prefer a particular voice. Semantic Bootstrapping (Pinker, 1989) proposes that children use semantics to learn arbitrary syntactic patterns, assuming that words with similar meanings (along specific dimensions) will behave similarly in syntax. While Pinker's theory required tight correspondences between meaning and syntax, Perfors et al. (2010) showed that Bayesian learners can benefit even from noisy correlations. In such a model, children need not assume that unseen verb–voice combinations are ungrammatical; instead, they can treat them as less probable given the overall distribution observed across verbs in the same semantic category. Exposure to additional input would allow learners to refine these probabilistic expectations and converge on the adult language. Together, our study provides a glimpse into the learning mechanism through which semantic regularities in the input could support the acquisition of voice systems in Austronesian languages.

Exactly how much learners of Austronesian languages would benefit depends on how strong the correlations are, which remains to be seen. If these correlations prove strong enough to facilitate learning, this mechanism would then appear to be a viable alternative to theories where language learning depends on a strong relationship between agent and subject or where the existence of sentential subjects are themselves reflexes of the primacy of causal agents in cognitive representations of events.

Acknowledgments

We acknowledge the use of large language models to assist with code drafting, data processing scripts, and preliminary text editing during the research process. All analyses, interpretations, and final decisions were carried out and verified by the authors, who take full responsibility for the content of this work. The authors would like to thank the Data Science Statistical Cooperation Center of Academia Sinica (AS-CFII-111-215) for statistical support.

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