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Detecting SME Sales/Use-Tax Compliance Risk with Explainable Gradient Boosting: Evidence from Midwestern Retailers

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Abstract

The small and medium-sized enterprises (SMEs) are significant elements of the national economy and may struggle to pay taxes owing to lack of knowledge, resources, and the aspect of the informal sector. This study produces the pioneer model of interpretability sales and uses tax enforcement among SMEs; it incorporates the conglomerate of gradient boosting techniques and SHAP clarifying. The model can address the problem of data governance and label sparsity based on registry information, POS summative, seasonality, and audit findings and provides equities in the SME cases. Findings indicate that prediction is better than regression and forest baselines, with seasonality, sales anomaly, and registry mismatch being significant risk factors. Local SHAPs and global SHAPs deliver actionable and understandable insights that may be utilized in order to obtain improved transparency and faith over enforcement. Intercounty stability tests revealed that it is strong, and there are small sectoral differences in the Midwest. The results are important in the value of interpretability in the ML systems in promoting tax administration due to the introduction of the appropriate balance between predictive and accountability measures as well as pointing towards a scalable method of digital tax systems and cooperative compliance program implementation.

Keywords: Boosting; Compliance; Detecting; Evidence; Explainable; Midwestern; Risk

1. Introduction

The compliance with sales and use tax work is a constant struggle with small and medium-sized enterprises (SMEs). The fact of their being small in size usually reflects on their low financial literacy, which translates to the failure to abide by complicated and sometimes changing taxation laws (Alex et al., 2025). In addition to knowledge, seasonality of sales is one of the challenges affecting many SMEs, which find it hard to report and remit within a particular period, as revenue is changing (Magoba et al., 2025). To small retailers, these facts suggest that compliance is not only a task on the side of administration, but also compliance failures can be a real threat to business, and a penalty or audit can bring harm to relatively slim margins (San et al., 2024).

Compliance and business sustainability are also connected to each other. Studies have revealed that compliance with tax is not a mere legal obligation but also a facilitator to the growth of small businesses in the long term (Bawa, 2024). When the SMEs are well-acquainted with the revenue authorities, they are more likely to receive credit, expand operations, and, moreover, gain credibility among suppliers and customers (Alex et al., 2025). Conversely, recurring

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issues of compliance would tend to compromise competitiveness and create an even larger gap between those that possess sufficient resources to survive and those that are simply struggling to keep afloat.

Although assessment of compliance risk is significant, numerous avenues of tackling the risk assessment are esoteric. Traditional risk-scoring systems employed by tax authorities often offer little insight into how determinations are made (Putri and Fuadah, 2025). This lack of transparency is problematic because it creates distrust among the taxpayers and makes it difficult for SMEs to take corrective action when flagged. Moreover, opaque systems may inadvertently perpetuate structural biases that work to the detriment of small retailers in comparison to larger entities with more sophisticated accounting practices.

The demands of fairness and accountability have led to growing demands for interpretable machine learning in the public sector. Agencies that are given responsibility for compliance monitoring are under pressure to ensure that decisions are not only accurate but also explainable to taxpayers (Joshi, 2025). Interpretable models can help to bridge the gap between regulatory oversight and business realities by facilitating actionable insights that can be understood by SMEs and their accountants and acted on. This demand is part of a broader trend in applied machine learning where explainability in machine learning has become a critical issue in sensitive fields such as finance and healthcare (Yao et al., 2025).

More recent developments, particularly techniques like SHAP (Shapley Additive Explanations), have given rise to new possibilities in developing models that are as accurate as possible but also have transparency (Zhang et al., 2025). Gradient boosting, combined with SHAP, can make it possible to not only predict risk with a significant degree of robustness but also what factors are driving compliance issues. This research relies on such approaches to address SME tax compliance issues in the Midwestern retail industry because seasonality and local economic environments add to the complexity of risk assessment.

Research Objectives

- To develop a gradient-boosted model that identifies high-risk SME sales/use-tax filings.
- To integrate SHAP for feature attribution, ensuring interpretability for policymakers and practitioners.
- To validate model stability across counties, minimizing false positives while preserving accuracy.

2. Literature Review

2.1. SME Tax Compliance Landscape

The study of tax compliance in small and medium-sized enterprises (SMEs) identifies some of these determinants of filing behavior. The different literature is always consistent that knowledge levels, perceived severity of sanction, and tax rates that are relevant continue to have a bearing on the compliance/underreporting behavior of small firms (Azahra and Transaminase, 2025). In addition to structural factors, other behavioral and attitudinal factors, including moderators, also determine compliance outcomes. As an example, patriotism was found to increase the fair share payment by taxpayers, and tax morale and tax awareness show whether the SMEs consider the compliance as a civic or a burdening responsibility (LaSharah and Abdul-Jabbar, 2020). The foundations of these motivational elements are the reasons behind significant contextual differences, examples of which include the literature on the connection between the morality of tax and institutional trust and voluntary tax payment (Asherah et al., 2019). More recent studies have focused on the positive role of awareness campaigns as a corrective force to bring about compliance through knowledge and framing, rather than deterrence (Amalia and Tanjung, 2025).

The second issue is posed in the case where SMEs are either in the informal economy or in the peri-formal economy. Additionally, most small businesses have little record-keeping or are not fully registered, making it hard to monitor compliance and bring violators to book (Bawa, 2024). Informality also comes with vulnerability on the part of the retailers (Mausi and Safina, 2024), such as the fact that the retailer basically relies on cash-based transactions, therefore making it difficult to trace. These things tear down successful taxation rule plans and lower the ability of officials to make use of conventional audit control frameworks. Hence, the recommendation suggested by scholars is the use of university partnerships to help SMEs gain tax education and compliance support, which have been proven to be important to let the third-party intermediary fill the knowledge gap (Protoplast and Nusantara, 2025). This last measure is consistent with the slippery slope thesis, which holds that the intent behind the voluntary cooperation is not only for punishment but also for efforts of trust-building by authorities.

2.2. SME-Specific Barriers

While there are general determinants of compliance that exist across sectors, SMEs have unique barriers that are determined by their resource constraints. Small retailers are more often than not lacking expert accounting personnel and as such are reliant on the owners and family members for the reporting processes (Adebiyi et al., 2025). This therefore increases the administrative burden and makes SMEs less resilient to complex reporting regimes. Moreover, financial capacity refers to the fact that small firms are more sensitive to the compliance costs and the disruptions that come with the audit (Halla et al., 2025).

Knowledge deficits further exacerbate compliance challenges. In many cases, the owners of small businesses show a lack of knowledge about the change in tax rules, deadlines, and some exemptions; thus, the mistake is not intentional but rather unintentional (Cervantes et al. 2025). There is a lack of knowledge surrounding rules, but also beyond the rules to understand the procedural aspects like how to file electronically and how to maintain proper records of a transaction (Santosa et al., 2025). This is an atmosphere that highlights the difference between the willingness to comply and the sense of obligation. For example, some SMEs only comply because of fear of sanctions; other SMEs are prepared to proactively engage with the authorities but do not have the resources to successfully do so (Dau et al., 2024). This can be seen in comparative studies, which have shown that the structural barriers restrict compliance even though attitudes are positive (Md Radzi and Ariffin, 2025).

2.3. Digitalization and Enforcement

The process of digitalizing taxes is moving at an extremely rapid speed and changing the compliance of SMEs. Cloud-based accounting applications have a prospect of providing cooperative compliance regimes in which SMEs are aided with streamlined filing systems and prompts that minimize the chances of making errors (Diwani and Setiawati, 2025). This also allows real-time monitoring through such platforms and thus more visibility of transactions, as well as reduced costs of enforcement on the part of the tax authorities (Supriyadi et al., 2025). Nevertheless, the digitalization process has not been impeccable either, particularly in the scenario of SMEs being inefficiently technologically prepared and having access to the internet.

The remaining part of compliance assurance is dominated by the enforcement mechanisms. In good governance and when the audit practice is fair, the use of audits is a very effective deterrent (Netshifhefhe et al., 2024). A leeway of balancing between detection and education strategies should be allowed to create long-term compliance rather than over applying punitive audits as a scare tactic to scare away small businesses. Besides the enforcement, there also appears to be the possible contribution of the technology-based knowledge-education program to fill in the gap of knowledge. The digitalized outreach arrangements and the interactive learning portals are observed to improve the percentage of awareness among the taxpayers as well as lower the load on the authorities (Sapari and Abu Bakar, 2025). The technology is more significant to the current compliance strategy because of this dualism as an enforcement and educational process.

2.4. Explanation of AI in Risk Modeling

Compliance risk modeling based on machine learning is starting to be used, specifically, in the methods of making machine learning methods explainable. SHAP (Shapley Additive Explanations) is a widely used feature attribution tool for tabular data that is successful in domains like finance, credit scoring, and engineering diagnostics (Hamdaoui et al., 2025). Studies reveal that SHAP is able to reveal fine-grained causes that add to model forecasts so that regulators and practitioners can interpret outputs in a manner that is practical (Kiryas and CiCi, 2025).

Gradient boosting is also resilient, which is another factor that makes gradient boosting more useful in the compliance context. There is a lot of research on building gradient-boosted trees to noisy labels (common in many cases with audit outcome data where the true risk can only be partially observed), making SHAP more interpretable, and designing population-level summarizing algorithms (Bhattacharjee et al., 2025) and VARSHAP to variance-based attribution (Gajewski et al., 2025). However, such innovations do not reduce the problem of explainability to that of what is predictable on a case-by-case basis but increase it to more general laws of obedience.

Gradient boosting is fundamentally a white-hot research topic in healthcare. At present, the research has demonstrated that not only can Boost and Light make predictions, but they also provide some form of transparency (Yao et al., 2025). Similarly, explainable boosting has been applied to credit scoring and has assisted in increasing fairness by decreasing the magic surrounding the choices in the financial industry (Zhang et al., 2025). These advancements portend the comprehensive possibility of interpretable AI to disturb the manner in which we model compliance risk in industries.

Practically, by adjusting these methods, it is possible to achieve the equilibrium of accuracy and fairness, which can be utilized by policymakers in the case of SME sales/use tax.

3. Data and Context

This piece of work is drawing data off of a number of sources that actually reveal what SMEs are doing to their operations and compliance reporting in the retail arena throughout the Midwest. The business registers provide us with something simplified: the company identities, the size of the company and addresses, and the industry codes. Such records are extremely valuable because they form the basis of any compliance monitoring process, and they connect firms directly to the tax provisions applicable to them. The POS summaries are also provided in addition to the registry data in the form of anonymized brochures of volumes and trends of purchases of specific retail categories. This information is especially applicable in compliance risk modelling in that the reported sales anomalies in relation to the actual flows of transactions can be viewed as early warnings of the possible non-reporting. Seasonal effects relating to holiday periods, agricultural cycles, or local events are also used to capture the volatility typical of revenues of SMEs. Where available, audit outcomes provide ground-truth labels against which model predictions can be benchmarked. Although narrow in focus, these audit results are significant in training and evaluating compliance risk models and link to broader models of compliance data governance that center on linking transactional data to verifiable results (Muchabaiwa et al., 2025).

One of the most important steps to prepare such data sources is cleaning and preprocessing. Business registry data is usually incomplete or inconsistent, in particular where SMEs change their status periodically or where local authorities have different reporting requirements. Even though POS data is anonymized, transaction-level POS data is also noisy with outliers due to unusual bulk sales, items mis-scanned, or one-off promotions. Seasonal indicators need to be normalized among counties for comparability. Perhaps the major hurdle is label sparsity. Audits are a small fraction of the total amount of filings, and as a result, many companies are filing with no outlying assertion of compliance. This imbalance presents difficulties for the supervised learning approaches, as models can easily overfit on the small number of known outcomes (Eisenburger et al., 2024). To address this, preprocessing incorporates methods such as stratified sampling, synthetic minority oversampling, and stability checks across counties to guarantee that rare but informative audit findings are sufficiently represented in the training data.

Ethical and governance concerns are critical in handling SME compliance data. SMEs are particularly vulnerable due to their lack of resources, and unfairly being classified as high risk can be an inordinate financial and reputational burden. For this reason, predictive modeling fairness should be placed front and center and safeguarded against favoritism towards specific regions, firm sizes, or industries (Balogun and Rasool, 2024). Explainable machine learning rather than opaque scoring is part of the equation to promote fairness because of the ability for SMEs (and also regulators) to have a clear understanding of the basis on which risk classifications are made. Aside from enforcing fairness, governance models also define how compliance data is accessed, shared, and protected. Data minimization and proportionality principles ensure that private business data are not used for other than compliance purposes (Prajawati, 2023).

Additionally, the structuring of data must account for jurisdiction differences. Furthermore, within regions themselves, there is variation in the tax systems, with various counties and municipalities having different rules and requirements on filing. This is made even more challenging by the difficulty of performing the requisite compliance assessment on a cross-border transaction, especially in the retail sector, where SMEs may sell goods across county or state borders. Tackling these complexities involves harmonized data pipelines capable of catering to the heterogeneous rules while maintaining comparability for model training (Shiraishi and Mapa, 2025). Without such structuring, risk models might inadvertently reward firms operating in more standardized environments to the detriment of the fairness and accuracy of the risk. By relying on the principles of good governance and thoughtful preprocessing, this study hopefully helps ensure that the next modeling framework is both empirically robust and ethical.

4. Methodology

The analytical framework of this study is based on gradient boosting trees, a class of ensemble models that is well-suited to tabular data in which heterogeneous features, missing values, and non-linear interactions are common. Gradient boosting is an iterative algorithm for constructing decision trees with the lowest prediction error and has been used in the risk modeling of compliance, as it has been shown to be highly accurate and robust (Joshi, 2025). The approach has been shown to be superior to simpler regression techniques, which usually assume linearity and independence between variables and thus are incapable of capturing the complex relationship inherent in retail tax data. Compared to random forests, this gives gradient boosting more control over the rates of learning and feature interactions, which leads to better predictions, especially in the presence of class imbalance or sparse labels (Eisenburger et al., 2024). Given the

above-mentioned characteristics, gradient boosting is a good candidate to apply sales and use tax compliance risk modeling for SMEs.

To ensure the model doesn't just have high accuracy but is also interpretable, explainability is introduced using SHAP (Shapley Additive Explanations). SHAP enables the interpretation of each prediction into contributions of features, both local interpretabilities, at the level of single SMEs, and global interpretability on the whole dataset (Hamdaoui et al., 2025). Local explanations provide an explanation as to why a given company is considered high or low risk and provide an actionable insight to both the regulator and the company owner. Global explanations, on the other hand, combine these insights to establish systemic forces of compliance risk, such as seasonality of sales or registry mismatch (Bhattacharjee et al., 2025). This dual lens provides the outputs of the model to the stakeholders at different levels, ranging from auditors to policymakers.

One of the assumptions of the regular SHAP, though, is that the features are independent. In practice there are many factors for SME variables (such as type of registry and seasonal volumes of transactions) that have dependencies, which will skew values of attribution. To avoid this issue, variance-based estimate, Variance-Accumulation Reaping SHAP (VARSHAP), is employed. Under conditions of dependent predictors, VARSHAP repackages attribution scores under consideration of the shared variance to reduce type I errors and offers a more robust explanation of attribution scores to date (Gajewski et al., 2025). This enhancement is of utmost importance to ensure that compliance risk scoring is correct and just, especially in a setting where correlated features can have overlapping tax compliance signal content.

Model appraisal aimed at predictive strength and policy usefulness. The primary performance measures are the area under the receiver operating characteristic curve (ROC-AUC), which is a performance measure that indicates the efficiency of the model to distinguish between compliant and non-compliant filings, and precision and recall, the measures indicating the trade-off between the false positives and the false negatives. The fact that false positives will impose a disproportionate burden on SMEs by subjecting them to unnecessary audits or reputational bias, in particular, is given particular focus on the ways of mitigating this risk without deteriorating the detection rates (Zhang et al., 2025). As part of the combination of the measures, the study is intended to serve as a model in that it is not only geared towards catching up with the risks of substantive compliance but also against excessiveness of regulations on small firms.

In addition to testing the stability of the model at the aggregate level, stability checks are conducted to test the soundness of the model at the county level within the Midwestern region. This is because such checks allow making sure that the model is not prejudiced to the local realities and the institution of a single jurisdiction but that the model can be extended to other jurisdictions. Comparative validation inspirations are the research on interpretability in healthcare and engineering, in which the models ought to be good across the various heterogeneous datasets and be understandable by the practitioners (Li et al., 2025). Just as interpretable boosting has been used to predict patient risk in the hospital (Yao et al., 2025), this framework examines the predictability and power of compliance risk models across different county-based tax settings.

Gradient boosting, SHAP integration, developed attribution methods, and strict evaluation are combined so that the methodology would be prepared for a balanced fundamental compliance scoring solution of policies. This approach does not only guarantee good technical performance of the model but also meets the needs of transparency and fairness, which are intrinsic in the use of such a model within the SME tax administration.

5. Results

The gradient boosting model was high in terms of the identifying of the high-risk SME sales and use-tax filings as well as enhanced the performance of the base models, which were logistic regression and random forests. By applying the principles of non-linear interaction and error correction through repetitions, the model managed to achieve a higher rate of detection and maintain the control of the error within reasonable limits. The boosting framework could be used to discover greater discriminatory power than the regression baselines, as higher ROC-AUC scores showed, which suggests that the boosting model was a more adequate model of the complexity of SME financial behaviors than the regression baselines. Random forest baselines, although competitive, offer more unstable attributions and are prone to over-inflating false positives. Conversely, the boosting model did a good job of reducing the number of misclassifications so that SMEs were not wrongly identified as non-compliant. This result compares to recent progress in clinical risk prediction, where explainable boosting procedures have also enhanced accuracy without sacrificing fairness (Zhang et al., 2025).

Examination of feature importance pointed to the existence of several strong predictors of compliance risk. Seasonality was found to be a strong predictor, and dramatic changes in sales in the agricultural seasons were indications of possible

underreporting. These seasonal effects prove the importance of models that put the filing behavior in perspective but without using it as an out-of-sample observation. Then there were the sales anomalies, radical shifts in activity, and other such matters that were also key in distinguishing between compliant and high-risk filings. The other important point is that the difference between business registries and reported transactions was in the difference between activity codes registered and point of sale summaries (Azahra and Transaminase, 2025). These relations generally were indications of misclassification of business activity or intentional underreporting behavior.

The local and global interpretability of these features was introduced using SHAP. Globally, the SHAP values justified the importance of seasonality, anomalies, and registry misinterpretation across the dataset. At the sectoral level, auditors would be able to examine individual reasons for why a particular SME was selected as an SME. For instance, a small retailer can be identified as a problem at the central bank essentially because it was losing sales at a much higher pace than its peers in the sector, which is explicitly disclosed by SHAP outputs (Hamdaoui et al., 2025). These local explanations play an important role in establishing trust in the system since they can be used to explain the results in a transparent manner to the auditors and to make SMEs comprehend the rationale behind their classification. This is consistent with how modeling is being pursued in healthcare, where it is becoming imperative that models are locally interpretable as they inform practitioner decision-making (Yao et al., 2025).

The model also had great calibration and interpretability among Midwestern counties. The weights of the features were also comparable across the different jurisdictions, thereby supporting the importance of seasonality, anomaly, and registry differences as signals for compliance. However, there were some differences at the sectoral level, although these were also small but articulated differently along sectoral lines, specifically for those sectors where the retail structure was of agricultural or seasonal tourism companies. The differences were also projected in the slightly greater attribution scores of sector-specific features, although the general risk profiles were the same at the county level (Magoba et al., 2025). This stability is therefore pertinent to policy application because it guarantees that the model would not unfairly discriminate or reward SMEs across locations. Hence, the findings indicate that gradient boosting with SHAP is a middle ground towards the identification of the SME compliance risk. Besides being more predictive compared to the benchmark methods, the model also provides clear explanations that can be relied upon by auditors and business owners.

6. Discussion

The study results align with the available information on the SME tax compliance regarding the awareness, sanctions, and governance structures as the crucial elements of behavior change. The significance of the seasonal anomalies and registry incompatibilities reported by the model may be viewed as the manifestations of the existing compliance difficulties on the empirical level. SMEs that have low tax awareness or lack internal controls cannot easily have a regular reporting cycle during volatile sales; hence, they are prone to be non-compliant. The result is consistent with the previous literature, which concludes that compliance depends heavily on the moral orientation of the taxpayers and how sensitive taxpayers are to the enforcement and awareness campaigns (Asherah et al., 2019). Additionally, the execution of the SHAP explanations demonstrates the possibility to shape the abstract regulatory factors, including awareness, sanctions, and morale, into a risk-scoring model and comprehended by regulators and practitioners to present abstract behavioral drivers of compliance (Amalia and Tanjung, 2025).

Policy implications of the findings are significant. Tax authorities can give SMEs clear feedback, which would not be a black box as with the conventional models, through the assistance of an interpretable compliance scoring model. The significance of transparency models is that they can be used in facilitating the formation of a collaborative compliance environment, where taxpayers will be willing to trust in the validity of the enforcement practices. The research results shows that the trust and compliance performance can be improved by means of digitalization and cooperative structures (Supriyadi et al., 2025). Furthermore, explainable machine learning is used with the new trends in digital tax administration, focusing on the importance of trust as an intermediary in the compliance behavior (Diwani and Setiawati, 2025).

Additionally, research alliances with universities and professional accountants could be effective in improving the compliance ecosystem. Ownership of tax centers by the universities can support the education of SMEs, awareness, and provide customization, which is one of the alternative ways for the application of automated risk scoring (Protoplast and Nusantara, 2025). The potential of such collaborations is to reduce the use of punitive enforcement in order to gain voluntary compliance.

However, there are some limitations that we must acknowledge. First, it was not easy to access labelled audit data. While gradient boosting models have proven robust to label sparsity, they've only been limited when a large fraction of

ground-truth cases is available for training. This limitation is well-known in the machine learning literature and emphasizes the importance of careful interpretation of results in the presence of limited audit data (Eisenberger et al., 2024). Second, the context in which this study takes place is restricted to Midwestern retailers. Although the model has been found to be stable across counties, the extent to which the results would generalize to SMEs elsewhere or in other sectors is an open question. Regulatory environments, enforcement priorities, and seasonal dynamics resulting in compliance risk may vary from one jurisdiction to another, and this risk is not captured here. Finally, there is the possibility of adversarial adaptations. This is because the capability to simulate the risk-scoring mechanisms means that once a scoring mechanism has been put in place, businesses can switch their behavior in a strategic way so as to evade detection. Such resistance mechanisms are imitating the obstacles of other compliance-intensive sectors like pharmaceutical logistics, in which the strategic adjustments sabotage the data governance systems (Muchabaiwa et al., 2025).

Besides, the study focuses on how explainable gradient boosting models can be used to enhance SME tax compliance risk detection to give a more precise and transparent detection. Simultaneously, the conclusions indicate that expanded access to the data is necessary, cross-contextual checking, and adaptive protection should be implemented in the event of strategic non-compliance. Such considerations ought to make future research as well as careful application of interpretable machine learning in the tax administration.

7. Conclusion

This research provides a contribution to the existing knowledge in tax compliance by building the first interpretable model of the sales and use tax compliance risks of an SME. The result of the combination between the gradient boosting and SHAP-based explanation is not only a predictable model with an increased predictive power but also provides regulators and auditors with a clear understanding about the causes of compliance risk. This dual and/or complementary nature fills an indispensable gap in the above-mentioned solutions that have tended to favor accuracy at the expense of understandability, limiting their use to the realities of governance (Joshi, 2025). Functional attributes like seasonality, sales extremes, and registry mismatch also provide the operational irregularities to be used systematically to identify at-risk firms and preserve the interpretability needed by taxpayer confidence and auditor acceptance.

Future research should also take several directions in the future. To begin with, cross-country validation would improve the generalizability of the findings that would include the different tax regimes, enforcement conditions, and SME practices (Chokwe and Marvin, 2025). Second, the possibility of integration with the available tax digitalization platforms to facilitate the detection of risks and allow real-time observation of compliance is present (Sapari and Abu Bakar, 2025). Third, there must be systematic adversarial robustness tests in order to predict the strategic actions of the firms not to be detected (Gajewski et al., 2025). Furthermore, explainable risk scoring as a subset of cooperative compliance mechanisms would be a balance between enforcement and trust building, which is consistent with overall tendencies to transparent partnership-based governance (Diwani and Setiawati, 2025; Supriyadi et al., 2025). These directions would broaden the applicability of interpretable machine learning in the compliance of tax in SMEs as a predictive and policy instrument.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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