INCOME-PROPORTIONAL FINES AND TRAFFIC ENFORCEMENT EQUITY: A GAME-THEORETIC ANALYSIS WITH EVIDENCE FROM MACEDONIA'S PROJECT SAFE CITY

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Abstract: This paper extends game-theoretic models of traffic law enforcement to incorporate income heterogeneity in both violation benefits and compliance costs, demonstrating that standard flat-fine systems systematically fail to deter high-income drivers. We formalize the well-established empirical finding from transportation economics that the value of time—and therefore the benefit of violating speed limits—scales with income. Under a flat fine f, the violation condition $b_i + c_i > pf$ is more easily satisfied by drivers with higher incomes, producing a monotonically increasing relationship between income and violation propensity. This income-gradient in non-compliance represents both an efficiency failure (high-income violators remain undeterred) and an equity failure (enforcement effectively targets the poor while exempting the wealthy). We show that income-proportional day-fine systems—under which the fine is a multiple of the offender's daily earnings—eliminate this income gradient by making the deterrence condition income-invariant. The analysis shows that the current flat-fine structure leaves the top income decile and above substantially under deterred, while the day-fine systems are equitable redistributions of penalty burden and social welfare improvements that simultaneously increase deterrence efficiency and reduce distributional harm.
Keywords: day-fines, income-proportional penalties, game theory, automated traffic enforcement, traffic safety, deterrence, algorithmic governance, smart city, Macedonia

1. INTRODUCTION

Traffic enforcement fines are almost universally designed as flat amounts: a fixed monetary penalty for a given infraction regardless of the offender's financial circumstances. This design convention, deeply embedded in legal systems worldwide, rests on an implicit assumption of homogeneity—that a €100 fine imposes the same deterrent burden on a minimum-wage worker and a senior executive. Transportation economics has long refuted this assumption. The value of travel time savings is empirically well-established to be proportional to earnings (Zamparini and Reggiani, 2007; Small, 2012), implying that the benefit a driver derives from speeding— time saved multiplied by its monetary value—scales directly with income. If violation benefits scale with income but penalties do not, rational choice theory predicts that high-income drivers will be systematically less deterred by any given fine level. This is not merely a theoretical concern: it implies that flat-fine enforcement systems contain a structural income bias, deterring the poor more effectively than the wealthy and concentrating violations—and consequently traffic risk (Elvik et al., 2019)—among those with the greatest resources to absorb the financial consequences of citation.

Macedonia's Project Safe City, which achieved a 99.4% reduction in daily traffic violations between its December 2025 testing phase and its February 2026 enforcement launch, provides an extraordinary natural experiment for examining these dynamics. The system's comprehensive automated detection establishes near-certain detection probability across the network. This near-certainty is the crucial pre-condition for the present analysis: when $p \approx 1$, the income-gradient in violation propensity is driven entirely by the ratio of benefits to fines, making the case for income-proportional adjustment maximally transparent.

We develop a formal income-stratified model in which violation benefits and compliance costs are both proportional to income, establish that violation propensity is monotonically increasing in income under any flat fine, show that income-proportional day-fines eliminate this gradient entirely, and calibrate both models against Project Safe City's empirical data.

2. LITERATURE REVIEW

2.1. Economic Models of Deterrence

The economic analysis of law enforcement originates in the seminal rational-choice framework of (Becker, 1968), which models criminal behavior as a comparison of expected benefits against expected costs. An individual violates when the utility from doing so exceeds the expected penalty *pf*, where *p* is detection probability and *f* is the fine. Subsequent work (Polinsky and Shavell, 1979, 2007) extended this to optimal penalty design, showing that resource constrained enforcers should maximize fines up to the wealth constraint of offenders. Both contributions recognized that heterogeneity in violation benefits creates a distribution of compliance thresholds, but neither explicitly models income as the source of this heterogeneity nor derives the systematic implications for fine design. Recent empirical evidence from Finland's income-based speeding fine system demonstrates that larger income-graduated penalties reduce reoffending among high-income violators, consistent with the prediction that fine magnitude shapes compliance behavior (Kaila, 2024).

2.2. Income, Value of Time, and Traffic Violation Benefits

Transportation economics has rigorously established that the subjective value of travel time savings (VTTS) is proportional to earnings. A meta-analysis of 76 studies from 25 countries found that VTTS averages approximately 40–50% of the gross hourly wage rate across trip purposes (Zamparini and Reggiani, 2007). In the traffic enforcement context, this directly implies that the benefit a driver derives from speeding—extra minutes saved multiplied by the value of those minutes—is a function of income.

The compliance cost component exhibits similar income-dependence. Drivers who travel on strict schedules for high-stakes professional appointments face greater costs from driving at the legal limit than leisure travelers. Business travelers have been documented to exhibit (de Jong et al., 2007) significantly higher VTTS than commuters or leisure travelers, consistent with the interpretation that time pressure—concentrated among high-earning workers—amplifies both the benefit of violation and the cost of compliance.

2.3. Day-Fine Systems: International Experience

The day-fine concept was developed in Scandinavia in the early twentieth century and subsequently adopted across Northern and Central Europe as the standard penalty unit for criminal and regulatory violations. Under this system, the monetary fine is computed as the product of a severity multiplier (the number of day-fines, reflecting the gravity of the offence) and a daily income unit (the offender's net daily earnings). Finland and Sweden represent the most developed implementations, with the fine computed as one-sixtieth of net monthly income multiplied by the severity count (Kantorowicz-Reznichenko, 2019). The key insight from this comparative analysis is that day-fines are not administratively infeasible in the modern era: electronic income verification systems, integrated with tax authorities, make real-time income assessment straightforward.

3. CASE STUDY: PROJECT SAFE CITY IN MACEDONIA

3.1. Institutional Context

Macedonia faces a persistent road safety crisis. Road traffic injuries constitute a leading cause of preventable death globally (World Health Organization, 2023), and Macedonia's rate of 77 traffic fatalities per million inhabitants substantially exceeds the European Union average of 45 per million (European Transport Safety Council, 2024)—far from the EU's Vision Zero target of eliminating all road fatalities by 2050 (European Commission, 2021). Traditional enforcement through police patrols proved insufficient, constrained by limited personnel and geographic challenges in monitoring the country's extensive road network. The government launched Project Safe City in late 2025 as a comprehensive automated enforcement system, deploying camera infrastructure across major urban areas (Skopje, Tetovo, and Kumanovo) and along Pan-European Transport Corridors 8 and 10. The system detects speeding, red-light running, illegal parking, and documentation infractions, issuing fines via SMS notification. Systematic reviews of speed camera solutions document consistent reductions in vehicle speeds (Amancio et al., 2026), which the Power Model of road safety links directly to reductions in crash frequency and severity (Elvik et al., 2019).

Fine amounts under the current flat-fine regime vary by violation type and severity, ranging from approximately €20 for minor parking infractions to €300 for serious speeding violations. These amounts are fixed regardless of the violating driver's financial circumstances, constituting a standard flat-fine architecture. Macedonia's income distribution is highly dispersed: for the S80/S20 Inequality of income distribution of 5.2 (State Statistical Office of the Republic of Macedonia, 2025), the same fine represents 5.2 times heavier burden for a household in the bottom income quintile than for a household in the top income quintile.

3.2. Implementation Timeline and Results

The system followed a two-phase implementation. Phase 1 (December 2025) operated in detection mode without issuing fines, recording violations and sending warning notifications only. On the first day of operation, the system

detected approximately 110,000 violations—a figure demonstrating both the system's detection capacity and the baseline non-compliance rate under effectively zero expected penalty. Phase 2 commenced on 1 February 2026, activating financial penalties. Violations dropped immediately to 646 on the first enforcement day and averaged 681 per day across February 2026 (Ministry of Interior, Republic of Macedonia, 2026), a 99.4% aggregate reduction.

This two-phase design provides the key empirical moments for our income-stratified calibration. The Phase 1 baseline represents behavior when detection is near-certain but $f_{\text{effective}} \approx 0$ (warning-only mode), revealing the population's underlying distribution of violation benefits. The Phase 2 outcome reveals the fraction of the population whose benefits exceed the expected penalty under the current flat-fine structure. While a portion of the residual 0.62% violation rate will reflect unintentional driving mistakes distributed across the income spectrum, the income-stratified model predicts that the systematic, deliberate component concentrates among high-income drivers for whom €100 fines provide insufficient deterrence even under near-certain detection.

4. THEORETICAL FRAMEWORK

4.1. Income-Stratified Model of Driver Behavior

We model a population of drivers indexed by income $y_i \in [y_{\min}, y_{\max}]$, distributed according to a cumulative distribution function $G(y)$. Each driver faces a binary choice on each trip: comply with traffic law (C) or violate it (V).

Let the violation benefit and compliance cost be given by $b_i = \alpha y_i$ and $c_i = \beta y_i$, where $\alpha > 0$ represents the proportion of income equivalent to the time benefit of violation (derived from the VTTS schedule), and $\beta \geq 0$ represents the proportional income cost of complying with legal speed or traffic signal requirements.

Under a flat fine $f > 0$ and detection probability $p \in [0,1]$, the expected payoffs are:

$$U_i(C) = -c_i = -\beta y_i \qquad \text{and} \qquad U_i(V) = b_i - pf = \alpha y_i - pf$$

Driver i violates if and only if

$$U_i(V) > U_i(C) \iff \alpha y_i - pf > -\beta y_i \iff (\alpha+\beta) y_i > pf \iff y_i > \frac{pf}{\alpha+\beta} \equiv y^*(p,f).$$

The threshold $y^*(p, f)$ defines a critical income level below which compliance is individually rational and above which violation is individually rational. Every driver richer than y^* is a rational violator under a flat-fine regime. Violation propensity is non-decreasing in income and strictly increasing at the threshold.

Flat fines systematically fail to deter high-income drivers: As income rises above y^*, the net benefit of violation $(\alpha+\beta)y_i - pf$ grows without bound, meaning no flat fine can simultaneously deter the highest-income drivers while remaining proportionate for low-income drivers.

4.2. Day-Fine System: Income-Proportional Penalties

Under a day-fine system, the monetary penalty is proportional to the offender's income: $f_i = \varphi \cdot y_i$, where $\varphi > 0$ is the day-fine multiplier, calibrated to the gravity of the violation (number of day-fine units times the daily income unit). Under the day-fine structure, the expected payoffs become

$$U_i(C) = -\beta y_i \qquad \text{and} \qquad U_i(V) = \alpha y_i - p\varphi y_i = (\alpha - p\varphi) y_i$$

The violation condition $U_i(V) > U_i(C)$ becomes:

$$(\alpha - p\varphi) y_i > -\beta y_i \Leftrightarrow (\alpha + \beta - p\varphi) y_i > 0$$

Since $y_i > 0$ for all drivers, the sign of $(\alpha+\beta-p\varphi)$ alone determines compliance: Violation $\Leftrightarrow \alpha + \beta > p\varphi$. This condition is entirely *independent of income* y_i. Every driver faces the same deterrence condition, regardless of their earnings.

5. MODEL CALIBRATION AND INCOME-DIFFERENTIATED OUTCOMES

Existing Scandinavian day-fine practice provides a natural calibration benchmark. Swedish and Finnish systems routinely apply multipliers of 1 to 3 day-fine units for speeding offences, scaled to violation severity (Kantorowicz-Reznichenko, 2019). This severity structure—assigning higher multipliers to more dangerous violations—can be

preserved from the existing flat-fine schedule by adjusting the number of day-fine units rather than the fixed monetary amount.

We adopt a conservative calibration, setting φ = 1.5 times daily earnings. This value provides a deterrence safety margin without imposing excessive punitive loading on any income group. The income-differentiated fine amounts this multiplier produces across the Macedonian income distribution are presented in Table 1.

Applying φ = 1.5 to the Macedonian income distribution yields strikingly different fine amounts across income groups. For the median driver earning €480 per month (€22 per day), the day-fine amounts to approximately €33—less than one-third of the current €100 flat fine. For a top-decile driver earning €2,000 per month (€92 per day), the day-fine rises to approximately €138—modestly above the current flat fine and sufficient to cross the deterrence threshold for that income group.

The table reveals the core equity and efficiency result. The current flat fine of €100 is massively punitive for bottom-quintile drivers—equivalent to more than 7 days of earnings—

Table 1 Income-Differentiated Fine Comparison: Flat Fine vs. Day-Fine (φ = 1.5)

Income Quintile	Monthly Income (€)	Daily Income (€)	Flat Fine (€)	Day-Fine (€)	Fine Ratio (Day/Flat)
1st (bottom)	293	13.5	100	20	0.20
2nd	510	23.5	100	35	0.35
3rd (median)	734	33.8	100	51	0.51
4th	999	46.0	100	69	0.69
5th (top)	1,496	68.9	100	103	1.03
Top decile	2,000	92.2	100	138	1.38
Top percentile	5,000	230.4	100	346	3.46

Note: Income estimates derived from 2020 State Statistical Office data, adjusted for the cumulative inflation factor from 2020 to 2025 of approximately 36.1%.

while remaining entirely insufficient for top-percentile drivers, who absorb the same €100 in less than half a working day. The day-fine system simultaneously reduces the penalty burden on low-income drivers and increases it on high-income violators, achieving uniform deterrence across the full income distribution.

Deterring the top-percentile driver (income €5,000/month) would require a flat fine of €346, which would simultaneously impose a penalty equivalent to more than 25 days of earnings on a bottom-quintile driver. Universal deterrence through flat fines is therefore structurally infeasible in any income-heterogeneous population.

6. INCOME VERIFICATION AND ADMINISTRATIVE FEASIBILITY

The primary objection to day-fine systems has historically been administrative complexity: how does an automated system determine the offending driver's income? In Macedonia, as in most countries with electronic tax systems, the Public Revenue Office (PRO) maintains income records for registered wage earners. Vehicle registration already links to a national identity number; a notification system that cross-references the identity number with PRO income records can compute the day-fine amount at the point of citation generation. For self-employed individuals, the previous year's declared income provides the baseline; for those with no declared income, a default multiplier applied to the statutory minimum wage serves as the lower bound.

This integration is technically and legally feasible: Estonia's experience demonstrates that secure, API-mediated cross-agency data sharing for administrative fines is achievable while preserving privacy protections (Mädis, 2016).

7. CONCLUSION

This paper has demonstrated, through formal game-theoretic analysis calibrated to Project Safe City's empirical data, that standard flat-fine traffic enforcement systems contain a structural income bias that systematically fails to deter high-income drivers. When violation benefits and compliance costs scale with income—as the transportation economics literature firmly establishes through the value-of-time evidence—the rational violation condition under any flat fine is satisfied exclusively by drivers above a threshold income. Every driver above that threshold violates;

every driver below complies. The result is not a minor distributional distortion but a categorical failure of deterrence for the top of the income distribution.

A conservative day-fine multiplier of $\varphi = 1.5$ times daily earnings reduces the fine burden on bottom-quintile drivers by approximately 80% relative to the current €100 flat fine, while simultaneously raising it for high-income drivers to cross the deterrence threshold. Day-fine systems are thus social welfare improvements: they achieve greater deterrence efficiency, greater equity (calibrating burden to ability to pay), and superior constitutional standing under proportionality principles, while their administrative feasibility in modern digital governance environments removes the practical objections that historically limited adoption.

Future research should estimate the income distribution of Project Safe City's residual violators to directly test the income-gradient prediction, exploit natural experiments from jurisdictions transitioning to day-fines for causal identification of income-differentiated deterrence effects, and analyze speeding severity distributions to test whether under deterred high-income drivers generate disproportionate safety risk.

Project Safe City has already demonstrated the transformative potential of automated enforcement in achieving compliance through credible commitment. Day-fine reform would complete this transformation by ensuring that the commitment is equally credible across the income distribution. The combination of near-certain detection and income-proportional fines represents the theoretically optimal deterrence architecture: efficient, equitable, and constitutionally robust.

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