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Structural early warning in corporate credit: Evidence from a Brazilian agro-industrial distress episode

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Abstract

Accounting-based credit metrics can miss deteriorating fundamentals when leverage ratios remain stable but debt service dynamics shift. I apply the Leland and Toft (1996) structural credit model to Raízen S.A., Brazil's largest ethanol and sugar producer, over five fiscal years to March 2025 together with the December 2025 interim reporting date. The model flags elevated risk in FY2023/24 (nineteen months before the first negative rating action and twenty-three months before the loss of investment grade) while D/EBITDA held flat at 1.3× and agencies affirmed their ratings. The mechanism is the asset drift turning negative: debt service rose faster than market asset value, causing expected firm value to trend toward the default barrier even as accounting ratios showed no change. Benchmarking reveals that the Altman Z-score fails to discriminate distress in this capital intensive sector, while the Ohlson O-score confirms the timing but offers no economic interpretation. A peer comparison with two sector firms confirms the signal is firm-specific rather than sectoral. The case illustrates how structural models can complement traditional surveillance by capturing debt sensitive dynamics invisible to backward-looking ratios.

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1. Introduction

Accounting-based credit metrics are backward-looking and sometimes insensitive to market information. A firm's D/EBITDA may hold stable while its market-implied default probability rises, because the ratio encodes neither the cost of debt relative to asset value nor the risk-neutral trajectory of the underlying asset process. Structural credit models, originating with Merton (1974) and extended by Leland and Toft (1996), address this by modelling equity as a contingent claim on firm assets and default as an endogenous shareholder decision, generating a forward-looking diagnostic that complements accounting ratios.

Raízen S.A. (B3: RAIZ4), Brazil's largest ethanol and sugar producer, provides an illustrative case study. Between FY2021/22 and FY2023/24, D/EBITDA held in a narrow 1.3–1.5× band, consistent with investment-grade ratings from Fitch, S&P, and Moody's. A heavy second-generation ethanol (E2G) capex programme financed with debt collided with Brazil's policy rate tightening cycle (2% in 2021 to 15% by 2025), doubling interest expense and flipping the structural drift negative while leverage ratios showed no change. The first negative rating action came in October 2025, when Fitch placed the ratings on Rating Watch Negative. On 9 February 2026 all three agencies downgraded Raízen and the firm lost investment grade; Fitch's action took the rating from BBB− to CCC in a single step, the largest one-day move in recent Brazilian corporate credit history (Rio Times 2026). On 11 March 2026 the firm filed for out-of-court reorganisation (*recuperação extrajudicial*) covering approximately R$65.1bn of unsecured financial indebtedness, and the São Paulo bankruptcy court granted processing of the proceeding the following day. I show that an adapted Leland and Toft (1996) model flagged elevated risk in FY2023/24, nineteen months before any agency action and twenty-three months before investment grade was lost, contributing to the literature on structural early-warning models (Hillegeist et al. 2004; Bharath and Shumway 2008).

2. Methodology

Model. Firm asset value V_t follows a geometric Brownian motion under $\mathbb{Q}$: $\mathrm{d}V_t = (r - \delta)V_t\,\mathrm{d}t + \sigma_V V_t\,\mathrm{d}W_t$, where r is the Selic/CDI rate, $\delta = C/V$ the cash payout rate (C = gross interest expense), and σ_V asset volatility. Default occurs at the first passage of V_t below an endogenous barrier V_B^*, chosen by shareholders via the smooth-pasting condition $\partial E/\partial V_B = 0$ (Dixit and Pindyck 1994). The key diagnostic is the log-drift $\nu := r - \delta - \frac{1}{2}\sigma_V^2$: when $\nu < 0$, asset value drifts toward the barrier in expectation — a forward-looking signal accounting ratios cannot generate. Risk-neutral survival probability is $Q(T) = N(h_1) - e^{-\kappa x}N(h_2)$, with $h_{1,2} = (\pm x + \nu T)/(\sigma_V\sqrt{T})$, $\kappa = 2\nu/\sigma_V^2$, and $x = \ln(V/V_B^*)$. Distance to default is $\mathrm{DD}(t) = x/(\sigma_V\sqrt{t})$; following Crosbie and Bohn (2003), $\mathrm{DD} < 1.5$ signals elevated risk and $\mathrm{DD} < 1.0$ signals critical risk. Outstanding debt maturities are uniform on $[0,T]$ with continuous rollover. Firm value is $F = V + TB - BC$, where $BC = \alpha V_B^* \int_0^T A(s)\,\mathrm{d}s/T$ captures expected bankruptcy costs and $A(s)$ is the discounted default probability.

Interpreting the diagnostics. Three indicators provide early warning of distress. First, the log-drift ν: when $\nu < 0$, the expected path of asset value trends toward the default barrier rather than away from it. Second, distance to default DD: values below 1.5 indicate elevated risk, while values below 1.0 indicate critical risk (Crosbie and Bohn 2003). DD is reported here over the five-year debt horizon T, so the thresholds are applied on a sample-relative basis and are not numerically comparable to one-year distance-to-default measures. Third, the barrier ratio V_B^*/V: higher values indicate greater proximity to default. These diagnostics are forward-

looking, incorporating market equity prices and volatility that accounting ratios do not capture.

Tax shield. I condition the tax shield on profitability: $\tau_c = 0.34$ (IRPJ + CSLL local taxes) when net income is positive, and $\tau_c = 0$ otherwise (Graham 2000). A loss-making firm has no taxable income to shield; firm value then collapses to $F = V - BC$, the Modigliani–Miller world with costly default (Modigliani and Miller 1958).

Parameters. Raízen's fiscal year ends 31 March; the December 2025 column corresponds to the 3Q FY2025/26 interim reporting date. Asset volatility ($\sigma_V = 35\%$) is calibrated from FY2022/23 (the only post-IPO period), with DD $= 1.64$ and $V_B^*/V = 0.277$, satisfying $\partial E/\partial V \approx 1$. The 60-day realised equity volatility at 31 March 2023 was $\sigma_E = 55.5\%$ (Yahoo Finance daily prices); with $E^{\text{mkt}}/V = 0.627$ (R\$48bn / R\$76.5bn) this yields $\sigma_V = 55.5\% \times 0.627 = 34.8\% \approx 35\%$. FY2021/22 is discarded because the post-IPO premium biases E/V; FY2023/24 onwards are discarded because proximity to the barrier violates $\partial E/\partial V \approx 1$. Bankruptcy costs are set to $\alpha = 35\%$, above the US benchmark of 20–25% (Andrade and Kaplan 1998; Bris et al. 2006), reflecting Brazil's longer insolvency proceedings and forced-sale discounts on agro-industrial assets. Debt maturity is $T = 5$ years; $V = E^{\text{mkt}} + D_{\text{gross}}$; C equals Interest Expense (Total) from the income statement. The Selic target rate, sourced from Ipeadata, proxies r at each fiscal year-end.

Benchmark models. To assess the incremental value of the structural approach, I compute two widely-used alternatives: the Altman (1968) Z-score and the Ohlson (1980) O-score. The Z-score is computed as $Z = 1.2X_1 + 1.4X_2 + 3.3X_3 + 0.6X_4 + X_5$, where X_1 = working capital/total assets, X_2 = retained earnings/total assets, X_3 = EBIT/total assets, X_4 = market equity/total liabilities, and X_5 = sales/total assets. Thresholds are: $Z > 2.99$ (safe), $1.81 < Z < 2.99$ (grey zone), $Z < 1.81$ (distress). The O-score yields $P(\text{default}) = 1/(1+e^{-O})$; following the literature, I flag $P > 25\%$ as elevated risk. Financial data are from Yahoo Finance; market capitalisation is computed from share prices at fiscal year-end.

3. Results

Table I presents the full LT96 model output. Panel B shows the structural alarm; Panel C shows that accounting metrics detected nothing until FY2024/25.

FY2023/24: structural alarm. In FY2023/24, $D_{\text{net}}/\text{EBITDA}$ held at $1.3\times$ with positive net income of R\$521mn, providing no accounting signal. Yet three structural indicators crossed warning thresholds: ν turned negative (-0.037) for the first time post-IPO; V_B^*/V rose to 0.397; and DD fell to 1.18. Five-year survival probability dropped 23 percentage points, from 92.5% to 69.0%. Interest expense rose from R\$3.8bn to R\$5.1bn while V contracted from R\$76.5bn to R\$61.4bn, pushing δ from 4.9% to 8.3%. The Selic easing was insufficient:

$$\nu_{\text{FY23/24}} = 0.1075 - 0.0830 - \tfrac{1}{2}(0.35)^2 = -0.037, \tag{1}$$

versus $\nu_{\text{FY22/23}} = +0.027$. The accounting ratio remained flat because EBITDA and net debt moved in proportion; ν inverted because floating-rate debt service grew faster than market asset value, which is not captured by D/EBITDA.

Table I: LT96 structural credit metrics, Raízen S.A. (RAIZ4), FY2020/21–December 2025

	FY20/21	FY21/22	FY22/23	FY23/24	FY24/25	Dec-25
Panel A: Inputs						
r (Selic)	2.75%	11.75%	13.75%	10.75%	13.25%[a]	15.00%
τ_c	34%	34%	34%	34%	0%	0%
C (R$mn)	409	1,809	3,782	5,098	5,258	9,800
δ	0.027	0.019	0.049	0.083	0.075	0.126
ν	−0.061	+0.038	+0.027	−0.037	−0.003	−0.038
Panel B: Model outputs ($\sigma_V = 35\%$, $T = 5$yr, $\alpha = 35\%$)						
V_B^* (R$bn)	6.7	16.4	21.2	24.4	38.2	50.0
V_B^*/V	0.444	0.170	0.277	0.397	0.543	0.645
TB (R$bn)	0.3	1.3	2.7	3.6	0.0	0.0
BC (R$bn)	0.5	0.0	0.1	0.9	2.8	6.4
Spread (bps)[b]	326	0	4	351	134	**571**
Q(5yr)	57.0%	98.6%	92.5%	69.0%	55.7%	34.8%
PD(1yr)	3.0%	≈0	≈0	1.1%	8.3%	24.1%
DD(5yr)[c]	1.04	2.26	1.64	**1.18**	**0.78**	**0.56**
Panel C: Accounting benchmarks (memo)						
Net income (R$mn)	996	3,149	2,441	521	−4,257	n.a.[d]
Net debt (R$bn)	7.5	13.8	20.4	19.2	34.3	55.3
D_{net}/EBITDA	2.4×	1.3×	1.5×	1.3×	3.1×	5.5×

Variable definitions. r = risk-free rate (Selic target at fiscal year-end); τ_c = corporate tax rate (34% when profitable, 0% otherwise); C = annual interest expense; $\delta = C/V$ = payout rate; $\nu = r - \delta - \frac{1}{2}\sigma_V^2$ = asset log-drift (negative implies drift toward default barrier); σ_V = asset volatility; T = average debt maturity; α = bankruptcy costs as fraction of asset value; V = firm asset value ($E^{\text{mkt}} + D_{\text{gross}}$); V_B^* = endogenous default barrier; TB = tax benefit of debt; BC = expected bankruptcy costs; $Q(T)$ = risk-neutral survival probability over horizon T; PD = probability of default; DD $= \ln(V/V_B^*)/(\sigma_V\sqrt{T})$ = distance to default. Raízen's fiscal year ends 31 March; Dec-25 is the 3Q FY2025/26 interim reporting date, with C stated on a last-twelve-months basis.

[a] The 13.25% Selic target was in force only between 29 January 2025 and 18 March 2025; Copom raised it 100 bp to 14.25% on 19 March 2025, twelve days before the 31 March fiscal year-end. Substituting 14.25% yields $\nu = +0.006$ in place of -0.003. Either way $\nu \approx 0$, and the FY2024/25 diagnostic rests on the barrier ratio and DD rather than on the sign of the drift.

[b] Credit spread floored at zero.

[c] Amber: DD < 1.5 (elevated risk); red: DD < 1.0 (critical risk), following the distance-to-default framework of Crosbie and Bohn (2003). Thresholds are applied to the five-year DD reported here and are not numerically comparable to one-year measures. FY20/21 is pre-IPO; E^{mkt} proxied by book equity.

[d] Raízen remained loss-making through the December 2025 interim period, hence $\tau_c = 0$; interim net income is not directly comparable to the annual figures reported for prior columns.

FY2024/25 and the structural rupture. By FY2024/25, DD had fallen to 0.78 while the spread reached only 134 bps, a combination explained by $\nu = -0.003$: the firm was near the barrier but with drift close to zero. D/EBITDA rose to $3.1\times$, belatedly confirming the structural signal. The equilibrium collapsed between March and December 2025: debt refinancing nearly doubled C (+86%), pushing δ from 0.075 to 0.126. The concurrent Selic increase to 15.00% offset only a fraction of this — a 175 bp rise in r against a 510 bp rise in δ — leaving $\nu = -0.038$. Spread reached 571 bps, DD fell to 0.56, and $Q(5\text{yr})$ contracted to 34.8%, three months ahead of the out-of-court reorganisation filed on 11 March 2026. $D_{\text{net}}/\text{EBITDA}$ stood at $5.5\times$ — a clear alarm, twenty-one months after the structural signal.

Bond market validation. The firm's international bond (Raízen Fuels Finance 6.25% 2032, ISIN US75102XAF33, Luxembourg Stock Exchange)[1] provides independent market validation of the credit deterioration timeline. The yield-to-maturity remained stable near 6.5% through early October 2025, then jumped from 6.74% (8 October) to 10.17% (13 October)—a 343 basis-point repricing coinciding with the first negative rating action. A second, more dramatic jump occurred from 9.69% (2 February 2026) to 28.30% (13 February), spanning the 9 February downgrades in which all three agencies stripped investment grade. Critically, the LT96 model signalled elevated risk (DD < 1.5) in March 2024, nineteen months before the bond market repriced in October 2025. This lag between the structural signal and market repricing is consistent with the model capturing forward-looking information that was not yet reflected in bond prices.

Benchmark comparison. Table II compares the LT96 signal with the Altman Z-score and Ohlson O-score. The Z-score remains in the grey zone (1.99–2.78) throughout the sample and fails to discriminate the distress episode. This appears to be a sector effect: high asset intensity relative to market capitalisation places Brazilian sugar/ethanol firms in the grey or distress zones regardless of actual credit quality. The O-score $P(\text{default})$ rises from 12.8% in FY2021/22 to 28.0% in FY2023/24, crossing the 25% elevated-risk threshold in the same period that LT96 DD falls below 1.5. Both models thus identify FY2023/24 as the inflection point, one year before D/EBITDA rose above $2\times$. However, while the O-score correctly flags elevated risk, it provides no economic mechanism.

Peer comparison. To assess whether the distress signal is firm-specific or reflects sectoral stress, I compute O-scores for two Brazilian sugar/ethanol peers: Jalles Machado (JALL3) and São Martinho (SMTO3). Table III reports the results. São Martinho's $P(\text{default})$ remains below 20% throughout (10.2%–19.0%), despite a similar D/EBITDA trajectory rising from $1.8\times$ to $3.0\times$. This firm did not enter restructuring and serves as a healthy control. Jalles Machado shows rising $P(\text{default})$ (14.3% to 34.8%), consistent with its deteriorating profitability (net income fell from R\$692mn to $-$R\$56mn over the period). The divergence between Raízen/Jalles and São Martinho suggests the elevated risk signals are firm-specific rather than sector-wide, supporting the validity of the early warning in the Raízen case.

Robustness and sensitivity. The FY2023/24 elevated signal (DD < 1.5) is robust to parameter variation. Across asset volatility $\sigma_V \in [25\%, 45\%]$, DD ranges from 1.46 to 1.02—all below the 1.5 threshold. Across debt maturity $T \in [3, 7]$ years, DD ranges from 1.39 to 1.06. Across bankruptcy costs $\alpha \in [20\%, 45\%]$, DD remains at 1.18 (bankruptcy costs affect credit spreads

[1] Bond yield data from Luxembourg Stock Exchange, luxse.com.

Table II: Early warning signal comparison: LT96 vs. Z-score vs. O-score

	FY21/22	**FY22/23**	**FY23/24**	**FY24/25**
D/EBITDA	1.3×	1.5×	1.3×	3.1×
LT96 model				
DD(5yr)	2.26	1.64	**1.18**	**0.78**
Signal	–	–	ELEVATED	CRITICAL
Altman Z-score				
Z	2.77	2.78	2.05	1.99
Zone	Grey	Grey	Grey	Grey
Ohlson O-score				
$P(\text{default})$	12.8%	19.2%	**28.0%**	38.3%
Signal[a]	–	–	ELEVATED	ELEVATED

[a] O-score signal: $P(\text{default}) > 25\%$ = elevated.

Table III: Peer comparison: O-score $P(\text{default})$ and leverage

	FY22/23	**FY23/24**	**FY24/25**
Raízen (RAIZ4)			
$P(\text{default})$	19.2%	**28.0%**	**38.3%**
D/EBITDA	1.5×	1.3×	3.1×
Outcome	Out-of-court restructuring (Mar 2026)		
Jalles Machado (JALL3)			
$P(\text{default})$	14.3%	25.8%	34.8%
D/EBITDA	0.7×	1.1×	1.3×
Outcome	No restructuring (stressed)		
São Martinho (SMTO3)			
$P(\text{default})$	14.1%	10.2%	19.0%
D/EBITDA	1.8×	1.6×	3.0×
Outcome	No restructuring (healthy)		

Market capitalisation from Yahoo Finance at fiscal year-end. Elevated threshold: $P(\text{default}) > 25\%$.

but not the distance to default). The negative drift $\nu < 0$ is particularly robust: it holds for all $\sigma_V \geq 22\%$, well below the calibrated 35%. Holding σ_V fixed, the entire 0.064 shift in ν between FY2022/23 and FY2023/24 is attributable to the payout and policy-rate channels: δ rose 3.4 percentage points (0.049 to 0.083) while r fell 3.0 percentage points (13.75% to 10.75%). The convexity term $\frac{1}{2}\sigma_V^2$ enters only as a level shift common to all periods, so it cannot generate the inversion. Strebulaev (2007) documents a similar pattern in US corporates: structural models lead accounting ratios precisely when payout rates exceed the risk-free rate.

4. Conclusion

This case study applies the Leland and Toft (1996) model to a distressed Brazilian firm and shows that the log-drift ν and distance to default crossed warning thresholds when investment-grade ratings were being affirmed. Two adaptations (a conditional tax shield and a single-period volatility calibration) make the framework operational for a loss-making, high-leverage emerging-market firm.

Benchmarking against widely-used alternatives reveals that the Altman Z-score fails to discriminate distress in this sector, remaining in the grey zone throughout. The Ohlson O-score confirms the timing of the LT96 signal but provides no economic mechanism for the deterioration. A peer comparison with São Martinho—which experienced similar leverage dynamics but remained healthy—confirms that the elevated risk signal is firm-specific.

The evidence from this single case is consistent with structural models providing incremental diagnostic value as a complement to traditional credit surveillance: monitoring ν and V_B^*/V alongside D/EBITDA could have provided material early warning. The key mechanism, i.e., debt service causing the asset drift to turn negative, has not been flagged by rating agencies or traditional accounting-based metrics. Broader validation across multiple distress episodes is needed before generalization in emerging-market contexts.

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