Musical Carbon Dating

A Regression Analysis of Music Evolution (1960–2020)

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University Statistical Analysis Project

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The Research Question

The Arrow of Time

"Can we define the 'Arrow of Time' for music using only audio signal properties?"

Objective: To quantify the evolution of musical production styles from 1960 to 2020 using Regression Analysis.

Why it matters:

- **Commercial**: Recommendation systems (Spotify) need to understand "vintage" vs "modern" aesthetics beyond just metadata.
- **Cultural**: Quantifying the impact of the Digital Revolution (1999).

The Dataset

Source: Spotify 600k Tracks Dataset.

Filtering Criteria:

- Year: $1960 \leq T \leq 2020$.
- Popularity > 30 (Focus on culturally relevant tracks).
- Cleaned $N = \mathbf{250,971}$.

Source: Yamac Eren Ay (Kaggle, 2021)

Features ($p = 13$):

- **Physical**: `loudness`, `tempo`, `duration`.
- **Perceptual**: `acousticness`, `energy`, `valence`.
- **Musical**: `key`, `mode`.

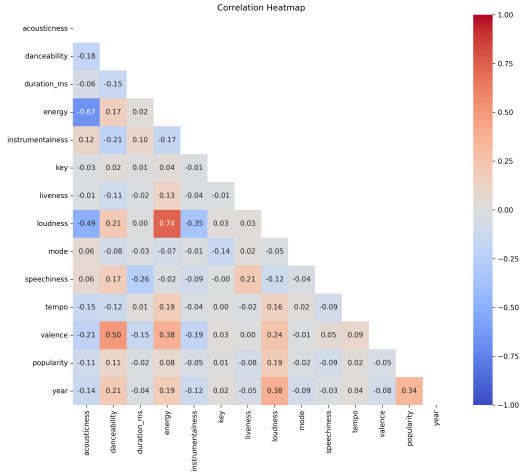


Figure: Feature Correlation Matrix (Note $r_{loud,energy} \approx 0.7$)

Phase II: Simple Linear Regression (The "Loudness War")

We started with a single predictor: **Loudness**.

$$y_i = \beta_0 + \beta_{loud} x_{i,loud} + \varepsilon_i$$

Result

- $R^2 = 0.144$.
- t-statistic $= 183.7$ ($p < 0.001$).
- **Interpretation**: Music has gotten significantly louder over time (+1.2 years per dB).

Phase III: Multiple Linear Regression (MLR)

We expanded to the Full Model ($p = 13$):

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon}$$

Model Performance:

- $R^2 = 0.296$.
- Test RMSE ≈ 12.06 years.

Key Insights:

- `Acousticness`: Strong negative trend ($\beta \approx -2.8$).
- `Danceability`: Positive trend ($\beta \approx +22$).

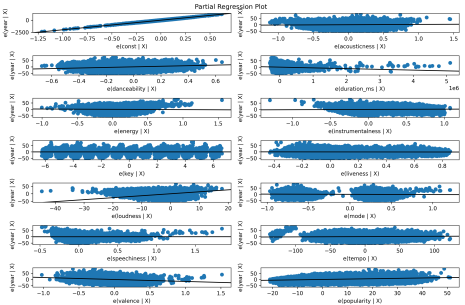


Figure: Partial Regression: Acousticness

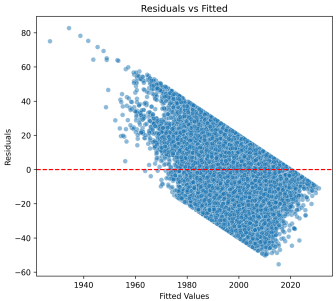
Phase IV: Diagnostics Overview

We rigorously tested the Gauss-Markov assumptions.

Assumption	Test Used	Outcome
Linearity	Partial F-Test (x^2_{dur})	Reject ($F = 304.7$)
Homoscedasticity	Breusch-Pagan	Reject ($LM = 19391$)
Multicollinearity	VIF Score	Pass (Max < 4.0)

Table: Diagnostic Summary

Residual Analysis: Boundedness & Heterogeneity



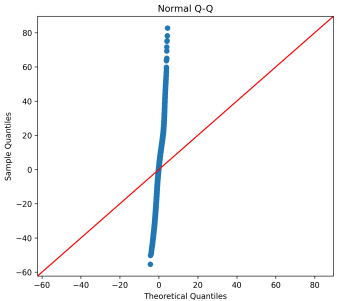


Figure: Residuals vs Fitted (Note the diagonal boundaries)

Boundedness Artifacts:

- $Y \in [1960, 2020]$ creates diagonal ceilings/floors ($e = y - \hat{y}$).
- Prediction space compressed at boundaries.

Heavy Tails (Q-Q Plot):

- Non-normal errors $\neq$ Model failure.
- Indicates **Stylistic Heterogeneity** (Retro/Futuristic outliers).

Remedy: Robustness via CLT ($N = 250k$). Non-normality justifies the **Nostalgia Index**.

Phase VI: The Digital Revolution

We hypothesized a structural break at $T = 1999$ (Napster & ProTools Era).

$$y_i = \mathbf{x}_i^\top \boldsymbol{\beta} + \delta D_i + D_i(\mathbf{x}_i^\top \boldsymbol{\gamma}) + \varepsilon_i$$

where $D_i = \mathbb{I}(Year \geq 1999)$.

Explanatory Result

- R^2 **Variance Explained**: $0.296 \rightarrow \mathbf{0.734}$ (Explanatory).
- **Interpretation**: This reflects the model's ability to fit the data once the "Digital Era" is accounted for.
- **Conclusion**: The mechanism of music creation fundamentally changed in 1999.

The "Scissor Effect" (Interaction)

Acousticness Coefficient Flip:

- **Pre-1999**: $\beta \approx -2.8$ (Folk/Rock era).
- **Post-1999**: $\beta + \gamma \approx +0.9$.
- **Meaning**: In the digital era, acoustic elements became a stylistic choice (e.g., "Unplugged") rather than a technological limitation.

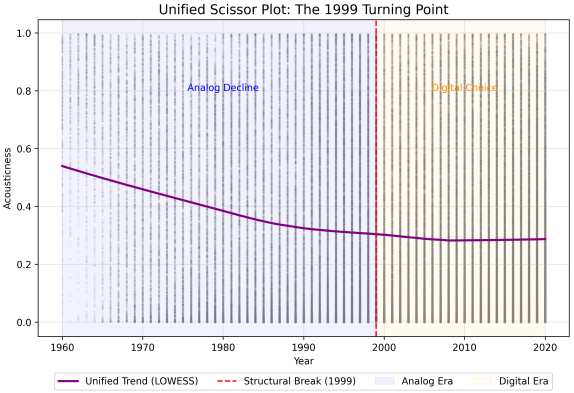


Figure: Unified Scissor Plot: LOWESS Trend

Phase V: Seeking Parsimony

We compared algorithms to select the optimal feature set.

Method	Criterion	Features	Verdict
Full Model	None	13	Baseline
LASSO	L_1 Penalty	12	**Preferred**
Stepwise	AIC	11	Too aggressive

Outcome: We retained complex features like `Instrumentalness` and `Speechiness` as they carry era-specific signal (e.g., Solos vs Rap).

The "Nostalgia Index"

We propose a **Retro Detector** metric:

$$\mathcal{N}_i = \hat{y}_{blind} - y_{actual}$$

- $\mathcal{N} \ll 0$: Song sounds older than it is ("Retro").
- $\mathcal{N} \gg 0$: Song sounds futuristic ("Avant-garde").

Song	**Actual**	**Pred**	**Δ (Yrs)**	**Vibe**
The Weeknd - *Echoes*	2012	1993.1	**-18.9**	90s R&B
Mark Ronson - *Uptown*	2015	2013.1	**-1.9**	Retro-ish
Dua Lipa - *Physical*	2020	2009.0	**-11.0**	80s Synth

Table: Verified Predictions on Test Set

Visualizing Prediction Accuracy

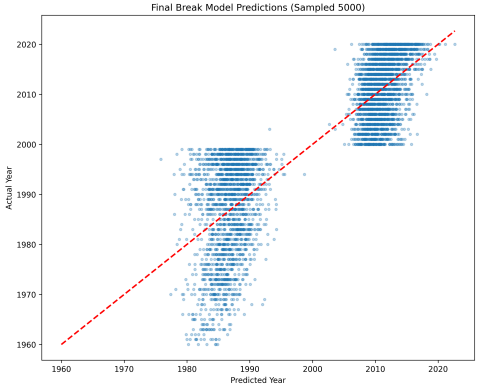


Figure: Actual vs Predicted (Test Set). Note the tighter fit post-1999.

Conclusion

1. **Success**: We can date music/audio with $RMSE \approx 7$ years (Era-Informed).
2. **Discovery**: 1999 was a structural singularity in music history.
3. **Utility**: The Nostalgia Index successfully identifies "Retro" hits.
4. **Curriculum Alignment**: Fully utilized SLR, MLR, Diagnostics, Ridge/Lasso, and Interaction effects.

Thank You

Questions?