Public Transport, Noise Complaints, and Housing

Evidence from Sentiment Analysis in Singapore

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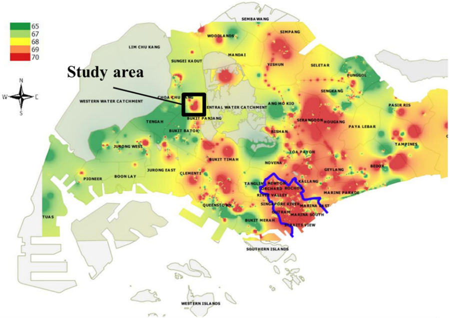
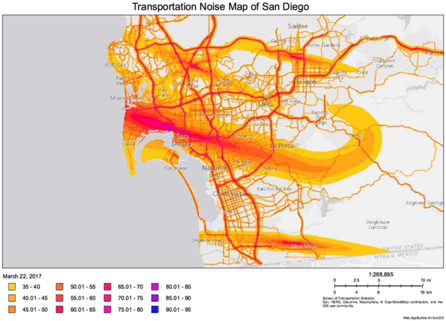
Noise Map (Contours) of Singapore and San Diego





Source: William Hal Martin & Diong Huey Ting (2017); US National Transportation Noise Map (https://maps.bts.dot.gov/)

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Consequences of Noise Pollution

- **Physical and Mental Health**
  - Cardiovascular disease, performance degradation, and stress process (Sørensen *et al.*, 2013; Münzel *et al.*, 2018).
- **Social Issues**
  - More violent behavior, higher crime rates and lower birth rates (Jamir *et al.*, 2014; Nieuwenhuijsen *et al.*, 2017).
- **Economic Losses**
  - Noise pollution generates larger loss than climate change in UK (UK Government, 2013).

Mixed Evidence from Public Transport

- **Positive Impact**
  - It is an important solution to address congestion (Anderson, 2014).
  - It increases the social welfare because of convenience (Monchambert & De Palma, 2014; Holmgren,2014; Chalak *et al.*, 2016).
  - Better accessibility enables social integration, which is associated with positive health outcomes (De Vos et al., 2013; Lucas, 2012).

- **Potential Negative Impact**
  - It results in air pollution, which offsets the benefits from accessibility (Chasco & Le Gallo, 2015; Higgins et al., 2019).
  - It generates traffic noise, while traffic noise causes loss of 1 million healthy life years annually (WHO, 2016).
  - Its noise potentially aggravates environmental inequality (Bilger & Carrieri, 2013; Nega et al., 2013) and decreases housing price (Ossokina & Verweij, 2015; Diao *et al.*, 2016; Friedt & Cohen, 2019).

Research Questions

Question 1

How does the intensification of public bus service impact resident's sentiment towards noise pollution?

Question 2

How does the negative sentiment toward residential noise impact the housing price?

Question 3

How much benefit from the convenience of public bus is offset by its noise impact?

Research Challenge

- **Measurements**:
  - Lacking reliable real-time measurements of noise levels and subjective human perceptions.
- **Endogeneity**:
  - Personal attributes related to both the selection of residential location and tolerance to noise.
  - Unobserved physical factors in the complex urban environment.
- **Identification**:
  - Separating the noise impact of public bus from the convenience of accessibility.

Methodology and Findings

- **Novel Data Set and Sentiment Analysis:**
  - Extracting sentiment scores from real-time noise complaint records using the Natural Language Processing (NLP) tools.
- **Instrument Variable (IV):**
  - Constructing theoretical least cost path as IV for a newly launched public bus service route (Faber, 2014).
- **Noise vs. Accessibility:**
  - Matching the travel origins and destinations to explicitly control for the change in accessibility.
- **Results:**
  - Living closer to bus route by 100 meters increases noise sentiment by 10 percentage points; more severe effect for medium floor levels (5^{th}-8^{th} floors), and for buildings near bus stops.
  - A price reduction of 3.3% with a 1-scale-point increase in noise sentiment; noise of bus offsets 18.8% of the benefit from convenience.

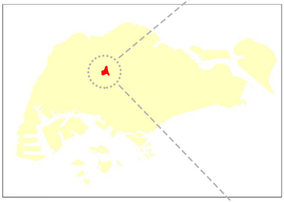
Contributions

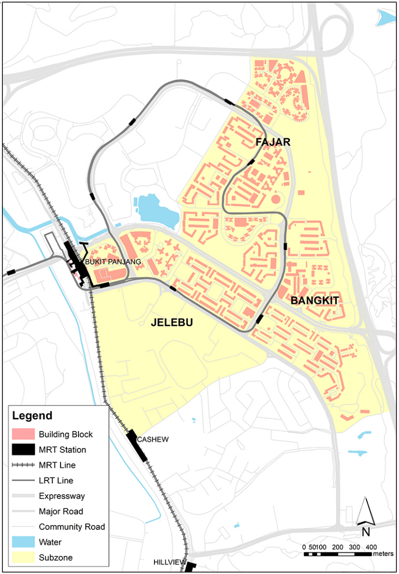
- **Policy Implication for the Noise Impact from Public Bus**
  - The common solution to the last-mile connectivity issue worldwide (Xie et al., 2010).
  - Significant public investment (NSW Budget Paper, 2019).
  - Potential environmental inequality.
- **Novel Data and Measurement**
  - The real-time measurement of noise is costly at individual building levels (Segura-Garcia et al., 2014).
  - Noise complaints database exists naturally in many cities worldwide.
  - Subjective perceptions better explain the noise impact on housing price (Boyle & Kiel, 2001; Chasco & Le Gallo, 2013, 2015; Friedt & Cohen, 2019).

Study Area: Public Housing (HDB) in Singapore

- **Basic Facts:**
  - Location: 3 subzones in Bukit Panjang District, Northwest Singapore.
  - Size: 1.2 sq.km
  - Buildings: 142 HDB blocks
- **Homogeneous Building Environment:**
  - Urban Form: Most of blocks was completed by the mid-1990s, and few new residential projects or redevelopments since then.
  - Maintenance: Regular maintenance and upgrading programs for all buildings in every 5 to 7 years.
  - Demographics: HDB accommodate more than 80% of the population, and the nationalities and ethnicity are evenly distributed.
- **Severity of Residential Noise**
  - Densely populated; close building distance; economical construction materials.
  - 70,000 noise complaints are made to government agencies annually (The Straits Times).

Map of the Study Area

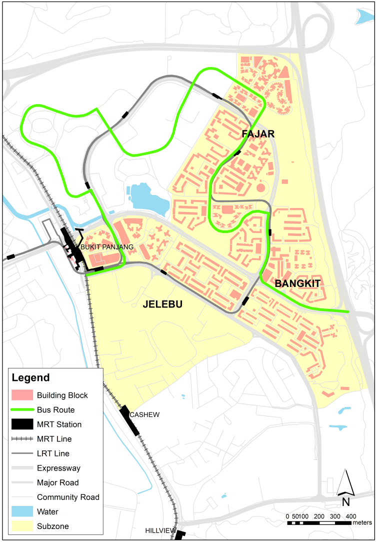




The New Bus Service

- **Public Buses in Singapore**
  - The most frequently used transportation mode (41.3%) among local working population.
- **Bus Service Enhancement Programme (BSEP)**
  - Increase the peak-hour public transport mode share to 75% by 2030
  - Grow the bus fleet by 35% before 2017
- **New Bus Service in Study Area**
  - Route No. 972, launched in November 2013.
  - Over 2.5 km long.
  - Designed to improve last-mile connectivity within community.
  - No other bus routes launched along a similar route from 2010 to 2018.

Map of New Bus Service Route



Data

- **Noise Complaint Records:**
  - Number of Records: 2,032
  - Period: March 2010 to February 2018
  - With full unit and demographics information: 527 (26%)
- **Sentiment Score Calculation:**
  - Winsorized top/bottom 1%
  - Normalized within 0 to 1.
- **Housing Transactions:**
  - Number of Records: 1,450 second-hand HDB resales transactions
  - Period: 2010 to 2017.
  - With noise complaints in the same building over past 1 year: 893 (62%)
- **Geo-location Information:**
  - Administrative boundary;building blocks; road networks; MRT and LRT lines; shopping centers and bus stops.

A Standard Difference-in-Difference (DID) Model

- It only captures the net impact of closeness to the new bus route on housing price (Diao et al., 2017).

$$log(Price_{ijt}) = \beta_1 Dist_i + \beta_2 Launch_t + \beta_3 Launch_t * Dist_i + X_i^{'}\theta + U_j^{'}\mu + \varphi_t + \omega_i + \epsilon_{ijt} \quad (1)$$

where:

- $Price_{ijt}$ is the total transaction price for unit j in block i sold at time t.
- SI_{ij}^{t} is the sentiment score from a complaint made at time t by a resident living in building i and unit j.
- $Launch_t$ is 1 if complaint time t is later than the launch of bus service, and is 0 otherwise.
- $Dist_i$ is the variation in the distance from each building to the new bus route.
- X_i is a vector controlling for building i's physical properties.
- U_j is the vector controlling for unit-specific properties.
- φ_t is the year and month time fixed effect.
- ω_i is the block fixed effect.
- ϵ_{ijt} is the error term.

Separate the Noise Impact: A 2-Step Approach

- **Step 1: Impact of Bus Route on Noise Sentiment (Baseline)**
  - A Modified DID Model
  - Challenge: Endogeneity Issue from the Bus Route.

$$SI_{ij}^{t} = \beta_1 Dist_i + \beta_2 Launch_t + \beta_3 Launch_t * Dist_i + X_i^{'}\theta + U_j^{'}\mu + \varphi_t + \omega_i + \epsilon_{ijt} \quad (2)$$

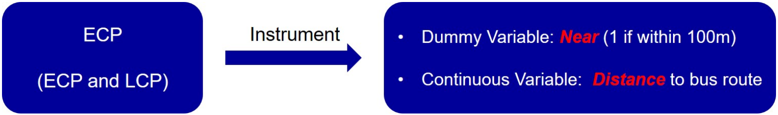
- **Step 2: Impact of Noise Sentiment on Housing Price**
  - A Time-Lagged Hedonic Model
  - Challenge: The impact from the change in accessibility on housing price is not separated.

$$log(Price_{ijt}) = \beta SI_{i,t-1} + X_i^{'}\theta + U_j^{'}\mu + \lambda M_t + \varphi_t + \omega_i + \epsilon_{ijt} \quad (3)$$

Notes: SI_{ij}^{t} is the sentiment score from a complaint made at time t by a resident living in building i and unit j.

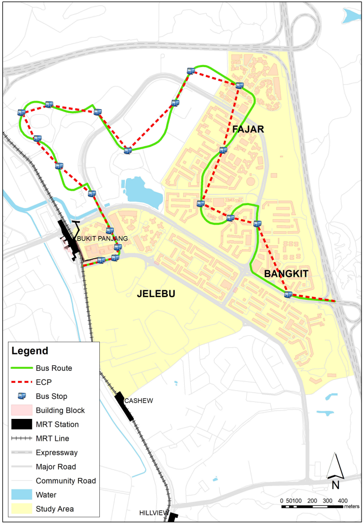
Theoretical Optimal Paths as Instrument Variable (IV)

- Distance to Theoretically Optimal Route (Faber, 2014; Jedwab *et al.*, 2017):
  1. Euclidean Cost Path (ECP) - Main IV: considering the original bus stops as the fixed nodes, use Euclidean straight lines to connect these nodes as the shortest path.
  2. Least Cost Path (LCP) - Robustness Check: considering the travel distance based on actual road network as the cost indicator and fixing only the bus entrance and exit points in the site, calculate the shortest commuting path.

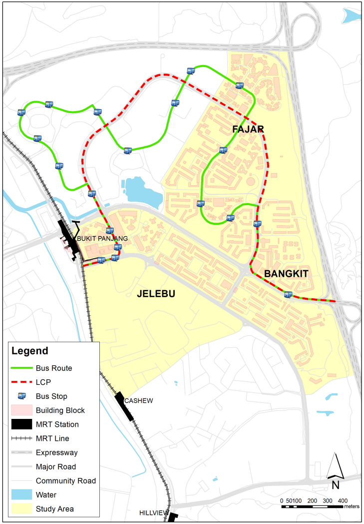


Map of Theoretical Optimal Paths

Euclidean Cost Path (ECP)



Least Cost Path (LCP)



Explicitly Controls for the Changes in Accessibility

- The new bus 972 connects the study area with CBD, while it zigzags on community road to solve last-mile connectivity.
- Before launching bus 972, the only bus (No.190) connecting the site and CBD runs on the major road only.
- We use distance to nearest bus stop before (by Bus 190) and after (by either Bus 190 or 972) treatment as proxy for change in accessibility.

Route of Bus No.190 (Old Bus)

Route of Bus No.972 (New Bus)

Baseline Results: First Stage Results of IV Estimation

	(1) ECP IV Launch*Distance	(2) Both IVs Launch*Distance	(3) ECP IV Launch*Near	(4) Both IVs Launch*Near
Launch*ECP	0.4184***	0.4025***	-0.3653***	-0.3306***
	(0.0520)	(0.0602)	(0.0546)	(0.0615)
ECP	-0.0070	-0.0491	0.0190	0.0367
	(0.0364)	(0.0395)	(0.0419)	(0.0451)
Launch*LCP		0.0491		-0.0787**
		(0.0352)		(0.0360)
LCP		0.1558**		-0.0790
		(0.0644)		(0.0651)
Launch	0.8278***	0.7932***	0.7781***	0.8410***
	(0.2051)	(0.2057)	(0.2049)	(0.2067)
First Stage F-Stats	32.67	38.07	22.69	26.81
Observations	527	527	527	527

Notes: Unreported control variables include gender, building age, floor, floor squared, building type, RC center, and the distance to train stations, LRT viaduct line, bus stops, expressways, major roads and shopping centers. Standard errors are clustered by buildings. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Baseline Results: OLS and IV Estimation

- Outcome variable: noise sentiment

	(1) OLS	(2) ECP IV	(3) Both IVs	(4) OLS	(5) ECP IV	(6) Both IVs
Launch*Distance	-0.0405	-0.0953**	-0.0965**			
	(0.0338)	(0.0430)	(0.0422)			
Distance	0.0074	0.0125	0.0301			
	(0.0328)	(0.0462)	(0.0423)			
Launch*Near				0.0496	0.1090**	0.1118**
				(0.0324)	(0.0459)	(0.0437)
Near				-0.0136	-0.0105	-0.0300
				(0.0303)	(0.0529)	(0.0476)
Launch	-0.0400	0.0319	0.0333	-0.1123	-0.1330	-0.1365
	(0.1167)	(0.1140)	(0.1114)	(0.1217)	(0.1069)	(0.1054)
Block&Time Fixed Effect	Y	Y	Y	Y	Y	Y
Observations	527	527	527	527	527	527
R-squared	0.213	0.206	0.208	0.214	0.203	0.207

Notes: Unreported control variables include gender, building age, floor, floor squared, building type, RC center, and the distance to train stations, LRT viaduct line, bus stops, expressways, major roads and shopping centers. Standard errors are clustered by buildings. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Robustness Check 1. Control Previous Exposure to Noise

- Outcome variable: noise sentiment

	(1) OLS	(2) ECP IV	(3) Both IVs	(4) OLS	(5) ECP IV	(6) Both IVs
Launch*Distance	-0.0367	-0.1511**	-0.1500**			
	(0.0430)	(0.0726)	(0.0698)			
Distance	-0.0141	0.0182	0.0477			
	(0.0431)	(0.0748)	(0.0672)			
Launch*Near				0.0396	0.1767**	0.1602**
				(0.0353)	(0.0859)	(0.0743)
Near				-0.0096	-0.0150	-0.0404
				(0.0346)	(0.0782)	(0.0669)
Launch	0.0579	0.1968	0.2075	0.0151	-0.0256	-0.0095
	(0.1594)	(0.1747)	(0.1739)	(0.1425)	(0.1321)	(0.1299)
Sentiment in Last Year	-0.0845	-0.0565	-0.0625	-0.0846	-0.0318	-0.0434
	(0.1161)	(0.1074)	(0.1089)	(0.1161)	(0.1074)	(0.1075)
Block&Time Fixed Effect	Y	Y	Y	Y	Y	Y
First-stage F-Stats		19.00	32.69		7.26	12.41
Observations	311	311	311	311	311	311
R-squared	0.273	0.255	0.261	0.270	0.225	0.246

Notes: Unreported control variables include gender, building age, floor, floor squared, building type, RC center, and the distance to train stations, LRT viaduct line, bus stops, expressways, major roads and shopping centers. Standard errors are clustered by buildings. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Robustness Check 2. Building Level Evidence

- Potential selection in excluding individual cases without complete unit-level information
- Use a 12-month window before and after opening of the new bus route at aggregated building level, following Faber (2014):

$$SI_i^{After} - SI_i^{Before} = \beta Distance_i + X_i'\theta + \epsilon_i \quad (4)$$

$$SI_i^{After} - SI_i^{Before} = \beta Near_i + X_i'\theta + \epsilon_i \quad (5)$$

where:

- SI_i^{Before} and SI_i^{After} are the average sentiment scores of noise complaints in block i recorded 12 months before and after launch of the new bus service.
- $Distance_i$ is the distance from block i to the actual bus route.
- $Near_i$ is the dummy variable indicating whether block i is within 100 meters of the actual bus route.
- X_i is the same vector controlling for building i's physical properties, as in the individual case-level estimation.

Robustness Check 2. Building Level Evidence

- Outcome variable: noise sentiment at building level

	(1) OLS	(2) ECP IV	(3) Both IVs	(4) OLS	(5) ECP IV	(6) Both IVs
Distance	-0.1095*	-0.1324*	-0.1484**			
	(0.0605)	(0.0741)	(0.0700)			
Near				0.0765	0.2037*	0.2201**
				(0.0660)	(0.1175)	(0.1056)
Building Age	0.0114	0.0112	0.0111	0.0127	0.0136	0.0137
	(0.0148)	(0.0129)	(0.0129)	(0.0147)	(0.0131)	(0.0131)
Slab Block	-0.0686	-0.0707	-0.0723	-0.0545	-0.0483	-0.0475
	(0.0780)	(0.0708)	(0.0721)	(0.0751)	(0.0785)	(0.0809)
RC Center	0.0687	0.0640	0.0606	0.0726	0.0411	0.0370
	(0.0579)	(0.0538)	(0.0538)	(0.0631)	(0.0761)	(0.0759)
First Stage F-stats		25.62	17.66		8.94	6.04
Observations	47	47	47	47	47	47
R-squared	0.245	0.242	0.237	0.215	0.119	0.092

Notes: Unreported control variables include the distance to train stations, LRT viaduct line, bus stops, expressways, major roads and shopping centers. Standard errors are clustered by building blocks. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Heterogeneous Effects Across Floor Levels

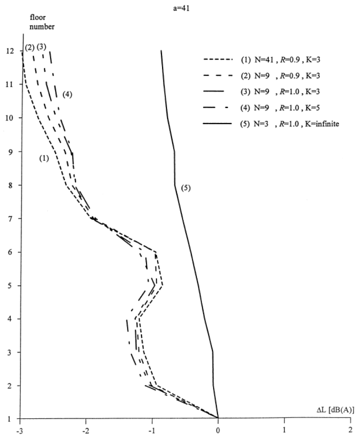
- Outcome variable: noise sentiment

	(1) 1-4 Storey	(2) 5-8 Storey	(3) Above 8 Storey	(4) 1-4 Storey	(5) 5-8 Storey	(6) Above 8 Storey
Launch*Distance	-0.0552	-0.2428***	0.0282			
	(0.0527)	(0.0820)	(0.0608)			
Launch*Near				0.0738	0.2141***	-0.0290
				(0.0674)	(0.0799)	(0.0802)
Block&Time Fixed Effect	Y	Y	Y	Y	Y	Y
First Stage F-stats	32.74	20.66	11.65	14.83	18.11	7.85
Observations	221	144	162	221	144	162
R-squared	0.479	0.598	0.564	0.477	0.605	0.544

Notes: Columns (1)-(3) report results for the continuous distance variable and columns (4)-(6) report results for the binary closeness indicator. All estimations use ECP, the Euclidean straight lines connecting bus stops, as the instrument. Unreported control variables include building age, floor and floor squared, gender, morphology, RC center, and the distance to train stations, LRT viaduct line, bus stops, expressways, major roads and shopping centers. Standard errors are clustered by buildings. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Heterogeneous Effects Across Floor Levels

Traffic Noise Simulation between Parallel Buildings (width = 41 m)



Reference: Walerian et al. (2001)

A Picture of Community Roads and Shade Trees in the Study Area

Heterogenous Effects Across Distance to Bus Stops

- Outcome variable: noise sentiment

	(1)	(2)	(3)	(4)
	Distance to Bus Stops			
	Within 100m	Out of 100m	Within 100m	Out of 100m
Launch*Distance	-0.2875***	-0.1330**		
	(0.0853)	(0.0607)		
Launch*Near			0.5114***	0.1315*
			(0.1924)	(0.0739)
Block&Time Fixed Effect	Y	Y	Y	Y
First Stage F-stats	38.59	26.27	17.24	21.35
Observations	179	348	179	348
R-squared	0.590	0.314	0.447	0.274

Notes: Columns (1)-(2) report results for the continuous distance variable and columns (3)-(4) report results for the binary closeness indicator. All estimations use ECP, the Euclidean straight lines connecting bus stops, as the instrument. Unreported control variables include building age, floor and floor squared, gender, morphology, RC center, and distance to train stations, LRT viaduct line, bus stops, expressways, major roads and shopping centers. Standard errors are clustered by buildings. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Impact of Noise Sentiment on Housing Price

	(1) Sample Buildings log(price)	(2) All Buildings log(price)
Sentiment	-0.0326**	-0.0300**
	(0.0160)	(0.0149)
Distance to Nearest Bus Stop Connecting CBD	0.0005	-0.0027*
	(0.0030)	(0.0016)
Prime Lending Rate	-2.4724***	-3.5344***
	(0.3513)	(0.4423)
Floor	0.0067***	0.0064***
	(0.0007)	(0.0005)
Area	0.0075***	0.0075***
	(0.0004)	(0.0002)
Building Age	-0.0018	-0.0035***
	(0.0012)	(0.0009)
Block & Time Fixed Effect	Y	Y
Observations	488	893
R-squared	0.927	0.919

Notes: Columns (1) include the same 47 building blocks in estimating the effect of bus route at building level. Column (2) include all the building blocks in the study area. Unreported control variables include the distance to train stations, LRT viaduct line, bus stops, expressways, major roads and shopping centers. Standard errors are clustered by buildings. Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Cost-Benefit Analysis

- Outcome Variable: log(price)

Effect of the New Bus Service on Housing Price			
	(1)	(2)	(3)
	net impact	negative noise impact	loss of benefit(%)
Close by 100 meters	0.0134***	-0.0031**	18.8%

- Column (1) reports the estimation result of Equation (1), using the same 47 building blocks in estimating the effect of bus route at building level.
- Column (2) reports the interpolated negative noise impact from our 2-step approach: We find that an increase of 1 scale point in noise sentiment is associated with a 3.26% decrease in housing price from Equation (3). Since living closer to the new bus service route by 100 meters has caused the noise sentiment score to increase by around 9.53%, the negative effect of its noise on housing price can be interpolated as approximately 0.31% per 100-meter distance to the bus route.

Conclusion

- **Bus Service and Noise Sentiment**
  - Living closer by every 100 meters, the negative sentiment increases by 9.5%.
  - On medium floors (5-8), this adverse effect has almost doubled.
  - The impact is stronger when close to the bus stops.
- **Cost Benefit Analysis: Noise Sentiment and Housing Price**
  - Increasing noise complaints by 1 scale point is associated with a 3.3% decrease in housing price.
  - Noise of bus implicitly leads to a decrease of housing price by around 0.31% per 100 meters closer to the bus route.
  - Public bus explicitly increases the price of units nearby (within 100 meters) by 1.3%.
  - Approx. 20% of the benefit from convenience is offset by noise.