Consumer and value creation in the utility of the future: An experiment in the Italian solar PV market

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Outline

1 Introduction

2 Theoretical background and research hypotheses

3 Sample

4 Methodology
- Design of the DCE
- Model and estimation technique

5 Results
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- Attribute importance and ranking
- Sensitivity analysis

6 Conclusions

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- Potential disruptive character of PV systems (and storage) linked to **prosumption**
- Level of prosumption and integration of PV system in the value chain dependent on **ownership** and **control** of the system (Watson, 2004; Sauter and Watson, 2007):
  - "Plug-and-Play" model
  - "Community micro-grid" (Blansfield and Jones, 2014)
  - "Company control" scheme
  - "Rent-a-roof" (Frantzis et al., 2008)

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- Decentralized energy storage not yet diffused

Related discrete choice experiments (DCEs) on HH preferences:

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$\Longrightarrow$HH preferences for innovative features of utility business models
to be investigated through DCE

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  $\longrightarrow$ **H_3: Purchase and installation through a professional installer (the "all-inclusive" formula) is the preferred sales channel.**

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⟶ **H_6: Respondents perceive benefits and costs of self-producing electricity differently**.

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- Online survey among 835 owner-occupied households in Italy: 423 PV system owners and 412 PV system non-owners
- Filtering criteria lead to 403 PV owners and 409 PV non-owners (12,180 observations)
- Data gathered in October 2014 using the CAWI technique

	PV owners (%)	PV non-owners (%)
Gender		
Male	63.1	58.5
Female	36.9	41.5
Age group (Years)		
18-34	26.2	30.8
35-54	56.5	47.8
55-74	16.5	20.9
≥75	0.5	0.5
Net household income (€)		
<24,000	14.9	26.2
24,000-35,999	26.0	27.2
36,000-47,999	20.3	16.5
48,000-59,999	13.7	9.7
60,000-71,999	6.6	3.9
72,000-83,999	5.0	3.4
84,000-99,999	1.7	1.5
≥ 100,000	3.3	1.5
I prefer not to reply	8.5	10.2
Geographical location		
North	39.7	42.2
Center	22.0	17.2
South	23.2	25.7
Islands	15.1	14.8

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- 15 choice cards + 2 identical holdouts
- Fractional-factorial and full-profile design
- Computer-optimized Complete Enumeration design method
- Presence of *ad-hoc* prohibitions across attribute levels

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Attribute	**Level**
A1. Control and maintenance of the PV system (CONTROL)	1.1 Your control and maintenance 1.2 Utility control and maintenance
A2. Total monthly benefits of the PV system (BENEFITS)	2.1 €60 per month for 20 years 2.2 €80 per month for 20 years 2.3 €100 per month for 20 years
A3. Monthly cost of the PV system (COSTS)	3.1 €0 (No ownership of the system) 3.2 €50 per month for 10 years (Your ownership of the system) 3.3 €70 per month for 10 years (Your ownership of the system)
A4. Duration of the supply contract with the utility (CONTRACT)	4.1 Not specified 4.2 1 year 4.3 5 years 4.4 10 years
A5. Purchase and installation of a battery storage device (STORAGE)	5.1 Yes, at no additional costs 5.2 Yes, at additional monthly costs of €60 for 20 years 5.3 Yes, at additional monthly costs of €80 for 20 years 5.4 No
A6. Channel of purchase and installation of the PV system (SALES)	6.1 Purchase via installer, "all-inclusive" formula 6.2 Purchase on-line, installation arranged by the vendor 6.3 Purchase in a shop, installation arranged by the vendor 6.4 Purchase from a salesman, installation arranged by the vendor 6.5 Purchase on-line/in shop/via salesman, installation organized locally by yourself

Example of a choice card

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Channel of purchase and installation of the PV system	Purchase on-line/in shop/via salesman, installation organized locally by yourself	Purchase on-line, installation arranged by the vendor	Purchase on-line/in shop/via salesman, installation organized locally by yourself	Tick this box if you would prefer not to install a PV system
Purchase and installation of a battery device	Yes, at no additional costs	Yes, at additional monthly cost of €80 for 20 years	Yes, at additional monthly cost of €60 for 20 years	
Total monthly benefits of the PV system	€100 per month for 20 years	€100 per month for 20 years	€60 per month for 20 years	
Monthly cost of the PV system	€70 per month for 10 years (Your ownership of the system)	€70 per month for 10 years (Your ownership of the system)	€70 per month for 10 years (Your ownership of the system)	
Duration of the supply contract with the utility	Not specified	Not specified	Not specified	
Control and maintenance of the PV system	Utility control and maintenance	Your control and maintenance	Utility control and maintenance	
	☐	☐	☐	☐

The Bayesian approach

- Widely employed in marketing studies
- Still rare applications in energy field (Train and Sonnier, 2005; Daziano, 2013)
- Estimation of a Hierarchical Bayes Multinomial Logit Model with Random Effects (Allenby and Lenk, 1994, 1995) within the Random Utility Theory Framework (McFadden, 1973)
- Individual parameters are random variables $\beta_i \sim MVN(\theta, \Lambda)$
- Hyperparameters θ and Λ are unknown: $\theta \sim N(q_n, Q_n); \Lambda \sim IW_p(d_0, D_0)$
- Bayes' Rule: $p(X|y) \propto p(y|X) * p(X)$
- Simultaneous estimation of all the parameters through MCMC simulation across 80,000 iterations

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Mean estimates of θ (Models 1, 2, 3 and 4)

Levels	Model 1	Model 2		Model 3		Model 4	
		Intercept	PV	Intercept	Age	PV	Non-PV
CONTROL_1	-0.172***	-0.240***	0.135**	-0.145*	-0.001	-0.097**	-0.322***
	(0.039)	(0.017)	(0.059)	(0.053)	(0.001)	(0.024)	(0.102)
CONTROL_2	0.172***	0.240***	-0.135**	0.145*	0.001	0.097**	0.322***
	(0.039)	(0.017)	(0.059)	(0.053)	(0.001)	(0.024)	(0.102)
BENEFITS_1	-0.024	0.068	-0.177**	-0.049	0.001	-0.096**	0.043
	(0.041)	(0.037)	(0.074)	(0.090)	(0.003)	(0.031)	(0.056)
BENEFITS_2	-0.031	-0.065	0.073	0.007	-0.001	-0.008	-0.089*
	(0.035)	(0.036)	(0.078)	(0.011)	(0.001)	(0.015)	(0.011)
BENEFITS_3	0.054	-0.003	0.105	0.042	0.000	0.103**	0.046
	(0.045)	(0.001)	(0.003)	(0.079)	(0.001)	(0.015)	(0.046)
COSTS_1	0.550***	0.833***	-0.546***	0.466**	0.002	0.305***	0.986***
	(0.068)	(0.088)	(0.056)	(0.109)	(0.003)	(0.057)	(0.069)
COSTS_2	-0.173***	-0.289***	0.215***	-0.095	-0.002	-0.066	-0.376***
	(0.044)	(0.009)	(0.035)	(0.037)	(0.001)	(0.057)	(0.072)
COSTS_3	-0.376***	-0.545***	0.331***	-0.371***	0.000	-0.239***	-0.610***
	(0.046)	(0.079)	(0.090)	(0.072)	(0.002)	(0.000)	(0.002)
CONTRACT_1	-0.080**	-0.038	-0.072	0.083	-0.004	-0.116**	-0.057
	(0.042)	(0.045)	(0.023)	(0.138)	(0.003)	(0.021)	(0.089)
CONTRACT_2	-0.121***	-0.121**	-0.003	-0.011	-0.003	-0.129**	-0.146**
	(0.043)	(0.044)	(0.016)	(0.061)	(0.003)	(0.055)	(0.024)
CONTRACT_3	0.100***	0.122**	-0.048	0.171	-0.002	0.071	0.160**
	(0.041)	(0.070)	(0.058)	(0.137)	(0.003)	(0.009)	(0.063)
CONTRACT_4	0.101**	0.036	0.123*	-0.243*	0.008**	0.175***	0.043
	(0.046)	(0.068)	(0.020)	(0.061)	(0.003)	(0.043)	(0.049)

⇒ Utility control is preferred

⇒ "Rent-a-roof" is preferred to "Plug-and-Play"

⇒ Contracts of longer lengths are preferred

Mean estimates of θ (Models 1, 2, 3 and 4), cont.

Levels	Model 1	Model 2		Model 3		Model 4	
		Intercept	PV	Intercept	Age	PV	Non-PV
STORAGE_1	0.726***	0.908***	-0.366***	-0.120	0.020***	0.559***	1.059***
	(0.060)	(0.023)	(0.063)	(0.050)	(0.002)	(0.0350)	(0.116)
STORAGE_2	-0.337***	-0.382***	0.121	0.167	-0.012***	-0.276***	-0.456***
	(0.057)	(0.013)	(0.017)	(0.167)	(0.004)	(0.003)	(0.040)
STORAGE_3	-0.412***	-0.491***	0.154*	0.026	-0.010***	-0.345***	-0.594***
	(0.059)	(0.052)	(0.142)	(0.103)	(0.001)	(0.063)	(0.066)
STORAGE_4	0.024	-0.035	0.091	-0.074	0.002	0.063	-0.009
	(0.054)	(0.041)	(0.096)	(0.014)	(0.001)	(0.025)	(0.090)
SALES_1	0.051	0.103*	-0.110	0.018	0.001	0.016	0.072
	(0.048)	(0.040)	(0.060)	(0.092)	(0.002)	(0.052)	(0.008)
SALES_2	-0.000	-0.004	-0.003	0.029	-0.001	-0.016	0.025
	(0.0490)	(0.078)	(0.010)	(0.005)	(0.001)	(0.004)	(0.017)
SALES_3	0.048	0.091*	-0.061	-0.002	0.002	0.022	0.111*
	(0.043)	(0.014)	(0.022)	(0.075)	(0.001)	(0.042)	(0.072)
SALES_4	0.052*	0.040	0.021	-0.190*	0.006**	0.045	0.098
	(0.040)	(0.037)	(0.042)	(0.112)	(0.001)	(0.060)	(0.127)
SALES_5	-0.151***	-0.230***	0.153**	0.145	-0.007**	-0.067	-0.306***
	(0.049)	(0.013)	(0.114)	(0.060)	(0.002)	(0.053)	(0.047)
None	-3.501***	-2.171***	-2.895***	-5.160***	0.036**	-4.271***	-2.184***
	(0.304)	(0.113)	(0.202)	(0.070)	(0.002)	(0.363)	(0.312)
McFadden's Pseudo R^2	0.5461	0.5474		0.5467		0.5003	0.6269

Level of credibility: *** = 99% ; ** = 95%; * = 90%.
Standard errors in brackets

⇒No ownership of battery is preferred

⇒ Installation arranged by vendor is preferred

Mean estimate of the variance-covariance matrix Λ and correlation coefficients (Model 1)

- Evidence of unexplained heterogeneity
- No evidence of correlation in parameters across choice tasks

	A1.1	A1.2	A2.1	A2.2	A2.3	A3.1	A3.2	A3.3	A4.1	A4.2	A4.3	A4.4	A5.1	A5.2	A5.3	A5.4	A6.1	A6.2	A6.3	A6.4	A6.5	None
A1.1	**.323**	-.323	.074	-.000	-.074	.047	-.048	.002	-.046	.001	.015	.031	-.042	.023	.076	-.057	-.009	-.011	.005	.006	.008	-.565
A1.2		**.323**	-.074	.000	.074	-.047	.048	-.002	.046	-.000	-.015	-.031	.042	-.023	-.076	.057	.009	.011	-.005	-.006	-.008	.565
A2.1			**.628**	-.139	-.489	.063	-.039	-.024	.061	.042	.004	.024	-.086	.068	.025	-.006	-.035	.022	.014	-.013	.012	-.283
A2.2				**.333**	-.193	.057	.041	.016	.044	-.009	-.025	-.011	.014	.019	-.010	-.023	.019	.013	.022	.011	.027	.344
A2.3					**.682**	-.005	-.002	.008	.017	.034	.029	-.013	.073	-.086	-.016	.029	.016	-.008	.008	.024	-.040	-.061
A3.1	.060	-.060	.521	.047	.004	**1.924**	-.896	-1.028	.019	-.009	.013	-.024	.327	-.159	-.192	.024	.002	-.019	.024	-.045	.038	1.558
A3.2	-.104	.104	-.609	.188	.004		**.654**	.242	-.003	-.006	-.016	.025	-.116	.076	.056	-.016	-.034	-.003	.010	.025	.002	-.647
A3.3	.004	-.004	-.487	.061	.015			**.785**	-.017	.015	.003	-.002	-.211	.083	.136	-.008	.033	.022	-.034	.020	-.040	-.912
A4.1									**.587**	-.022	-.245	-.320	.054	-.035	-.086	.067	.038	.011	.039	.029	.041	1.082
A4.2										**.554**	-.164	-.368	-.022	.014	-.011	.019	-.031	-.005	-.026	.008	.054	.134
A4.3											**.478**	-.069	.047	.002	.003	-.053	.003	.019	.019	-.010	-.031	-.491
A4.4												**.758**	-.079	.019	.094	-.033	-.010	-.002	.045	.031	-.064	-.725
A5.1	-.064	.064	-.095	.021	.077	.206	-.125	-.208					**1.313**	-.468	-.627	-.218	.061	.017	.030	-.067	-.041	1.707
A5.2	.056	-.056	.118	.045	-.144	-.158	.130	.129						**.526**	.149	-.207	-.024	.012	-.009	.004	.017	-.651
A5.3	.160	-.160	.038	-.021	-.023	-.165	.083	.183							**.702**	-.224	-.015	-.010	.007	.021	-.003	-1.375
A5.4	-.124	.124	-.009	-.049	.044	.021	-.025	-.011								**.649**	-.022	-.019	-.028	.042	.027	.318
A6.1																	**.560**	-.138	-.112	-.093	.216	.150
A6.2																		**.472**	-.136	-.135	-.063	-.196
A6.3																			**.465**	-.081	-.136	-.224
A6.4																				**.435**	.126	.044
A6.5																					**.541**	.225
None	-.184	.184	-.066	.111	-.014	.208	-.148	-.191	.262	.033	-.132	-.154	.276	-.166	-.304	.073	.037	-.053	-.061	.012	.057	**29.068**

Normalized and zero-centered β_i: Models 1, 4, 2, and 3

Levels	Model 1 All resp. N=812	Model 1 PV N=403	Model 1 Non-PV N=409	Model 4 PV N=403	Model 4 Non-PV N=409
CONTROL_1	-13.75	-10.05	-17.40	-7.35	-19.49
CONTROL_2	13.75	10.05	17.40	7.35	19.49
BENEFITS_1	-1.08	-4.60	2.39	-7.41	4.07
BENEFITS_2	-2.07	-1.00	-3.13	-0.12	-5.56
BENEFITS_3	3.15	5.60	0.73	7.53	1.49
COSTS_1	40.67	24.00	57.10	22.21	55.56
COSTS_2	-12.32	-5.52	-19.03	-4.50	-21.02
COSTS_3	-28.35	-18.48	-38.08	-17.72	-34.54
CONTRACT_1	-6.68	-10.19	-3.22	-9.51	-3.26
CONTRACT_2	-10.04	-11.09	-9.01	-10.49	-8.86
CONTRACT_3	8.34	8.72	7.97	5.69	10.40
CONTRACT_4	8.38	12.56	4.26	14.31	1.71
STORAGE_1	58.52	47.10	69.78	45.16	62.17
STORAGE_2	-27.69	-23.38	-31.52	-22.97	-26.65
STORAGE_3	-33.27	-26.26	-40.18	-27.97	-34.77
STORAGE_4	2.43	2.96	1.91	5.78	-0.74
SALES_1	4.17	1.93	6.39	0.65	5.08
SALES_2	0.11	0.83	-0.59	-0.79	1.50
SALES_3	3.59	3.07	4.10	1.68	6.13
SALES_4	5.12	6.06	4.19	4.37	6.54
SALES_5	-12.99	-11.88	-14.08	-5.91	-19.24
None	-328.00	-448.68	-209.08	-382.35	-139.76

Levels	Model 2 All resp. N=812	Model 2 PV N=403	Model 2 Non-PV N=409	Model 3 All resp. N=812	Model 3 PV N=403	Model 3 Non-PV N=409
CONTROL_1	-13.72	-8.68	-18.69	-13.91	-10.16	-17.61
CONTROL_2	13.72	8.68	18.69	13.91	10.16	17.61
BENEFITS_1	-0.86	-8.83	7.00	-0.83	-4.23	2.52
BENEFITS_2	-1.98	1.01	-4.93	-2.35	-1.26	-3.43
BENEFITS_3	2.84	7.82	-2.07	3.18	5.49	0.90
COSTS_1	40.98	21.46	60.22	40.46	24.05	56.63
COSTS_2	-12.80	-5.23	-20.25	-12.94	-5.94	-19.85
COSTS_3	-28.19	-16.23	-39.97	-27.51	-18.11	-36.78
CONTRACT_1	-6.17	-9.67	-2.72	-6.13	-9.49	-2.82
CONTRACT_2	-9.94	-10.80	-9.09	-10.69	-11.56	-9.83
CONTRACT_3	8.06	6.54	9.55	8.30	8.51	8.09
CONTRACT_4	8.05	13.93	2.26	8.52	12.54	4.57
STORAGE_1	57.55	45.74	69.18	57.77	46.41	68.97
STORAGE_2	-25.89	-22.72	-29.02	-26.23	-22.61	-29.80
STORAGE_3	-33.09	-28.81	-37.31	-33.65	-26.46	-40.74
STORAGE_4	1.43	5.79	-2.86	2.12	2.66	1.58
SALES_1	3.87	-1.22	8.88	3.29	1.19	5.36
SALES_2	-0.42	-0.15	-0.69	-0.59	0.17	-1.34
SALES_3	4.61	2.26	6.93	5.24	4.30	6.18
SALES_4	5.00	6.20	3.83	4.91	5.89	3.95
SALES_5	-13.06	-7.09	-18.95	-12.86	-11.54	-14.15
None	-337.79	-495.36	-182.53	-335.08	-456.65	-215.30

$\Rightarrow$ PV non-owners seem to be relatively more risk-averse than PV-system owners

Self-reported vs. estimated attribute importance (%) and ranking

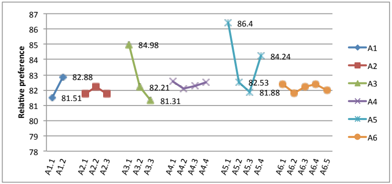
Table: Attribute ranking and Friedman test statistics

		Percentiles		
	Mean rank	25th	50th	75th
CONTROL	3.50	2.00	3.00	5.00
BENEFITS	2.75	1.00	2.00	4.00
COSTS	2.52	1.00	2.00	4.00
CONTRACT	4.02	3.00	4.00	5.00
STORAGE	3.82	3.00	4.00	5.00
SALES	4.40	3.00	5.00	6.00
N=812		$\chi^2(5) = 624.292$		p=0.000

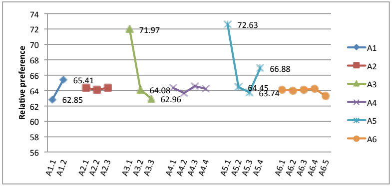
Table: Model 3 – Estimated average attribute importance (%) and ranking

Ranking	Attribute	All respondents (N=812)	PV owners (N=403)	PV non-owners (N=409)
1	STORAGE	23.74	22.27	25.19
2	COSTS	22.59	20.32	24.83
3	CONTRACT	16.64	18.07	15.22
4	BENEFITS	14.25	15.33	13.19
5	SALES	14.03	15.94	12.16
6	CONTROL	08.75	08.08	09.41
	Total	100.00	100.00	100.00

Computation of the variation in shares of preferences for a generic business model



(a) PV owners



(b) PV non-owners

A1: Level 1.5
A2: Level 2
A3: Level 2
A4: Level 2.5
A5: Level 2.5
A6: Level 3

Outline

1 Introduction

2 Theoretical background and research hypotheses

3 Sample

4 Methodology
- Design of the DCE
- Model and estimation technique

5 Results
- Posterior estimates
- Attribute importance and ranking
- Sensitivity analysis

6 Conclusions

Results suggest that:

- Greater attention placed on costs rather than benefits (H_6:✓)
- The "rent-a-roof" solution is preferred to "plug-and-play" (H_1:✓)
- External control and maintenance is preferred to internal one (H_4:✓)
- No preferences for ownership of the storage technology itself (H_2:$\times$)
- Overall no strong preferences for "all-inclusive" solution (H_3:?)
- Evidence for contracts of longer duration being preferred (H_5:✓)
- The effect of integration of decentralized renewable energy sources can be less disruptive as initially thought

Thanks for your attention!

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Backup slides

The framework

- Given *n* respondents, the individual-level utility for subject *i* of an alternative *k* across *j* choice tasks is $Y_{ijk} = \bar{Y}(x_{ijk}, b) + \varepsilon_{ijk}$, which under the assumption of a linear relationship between the attributes and utility becomes $Y_{ijk} = \beta_0 + x'_{ijk}\beta_i + \varepsilon_{ijk}$
- In each choice task *j* the alternative *k* picked by respondent *i* is assumed to maximize her utility $(Y_{ijv} \geq Y_{ijk})$, where *v* is the maximal latent utility achievable [1]

[1] Hess, S. and A. Daly, *Handbook of Choice Modeling*, Edward Elgar, 2014.

The model in details

- Choice probabilities can be written as: $P_{ij}(y = k|\beta_0, \beta_i) = \frac{exp(\beta_0 + x'_{ijk}\beta_i)}{\sum_{v=1}^{K} exp(\beta_0 + x'_{ijk}\beta_i)}$

- The joint probability distribution of all data and unknown quantities is:
$$\left[\prod_{i=1}^{n}\prod_{j=1}^{m_i}\prod_{k=1}^{K} P_{ij}(k \mid \beta_0, \beta_i)^{\chi(U_{ij}=k)}\right]\left[\prod_{i=1}^{n} h(\beta_i \mid \theta, \Lambda)\right] g(\beta_0)g(\theta)g(\Lambda)$$

- The marginal distribution of individual parameters can therefore be written as: $L(\beta_i) = \sum_{j=1}^{m_i}\sum_{k=1}^{K} \chi(U_{ij} = k) ln\left[P_{ij}(k \mid \beta_0, \beta_i)\right] + ln\left[h(\beta_i \mid \theta, \Lambda)\right]$

Heterogeneity distribution of β_i (Models 3, 4 and 16)

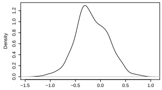

Figure: A1.1–Model 3

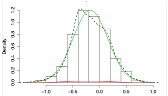

Figure: A1.1–Model 4

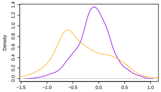

Figure: A1.1–Model 16

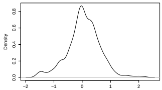

Figure: A2.3–Model 3

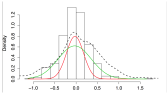

Figure: A2.3–Model 4

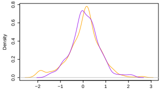

Figure: A2.3–Model 16

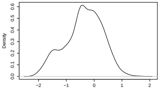

Figure: A3.1–Model 3

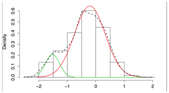

Figure: A3.1–Model 4

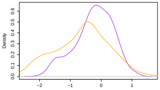

Figure: A3.1–Model 16

Heterogeneity distribution of β_i (cont'd)

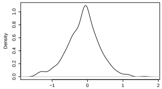

Figure: A4.2–Model 3

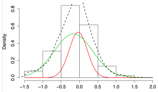

Figure: A4.2–Model 4

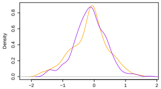

Figure: A4.2–Model 16

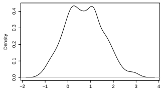

Figure: A5.1–Model 3

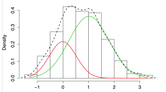

Figure: A5.1–Model 4

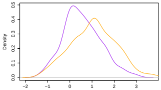

Figure: A5.1–Model 16

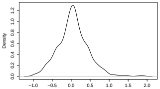

Figure: A6.1–Model 3

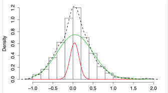

Figure: A6.1–Model 4

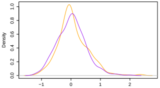

Figure: A6.1–Model 16