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Psychological and Behavioral Effects of Introducing a Demand-based Time-of use Electricity Distribution Tariff

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Project title and aims

Market based policy instruments in the residential sector

The overall aim of the project is

- to quantify residential response to a demand-based time-of-use electricity distribution tariff and

- to enhance knowledge on householders' drivers and barriers for shifting electricity use from peak to off-peak hours.

Swedish Energy Agency

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Tariff features

- Time-differentiated (time-of-use)

  peak hours: 7 am - 7 pm on weekdays

  off-peak hours: 7 pm - 7 am on weekdays and weekends

  summer season: April - October

  winter season: November – March

- Demand-based

  SEK/kW

  the costs are based on the average of the 5 highest meter readings in peak hours

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Study design and sample

Housing area

Form of housing	Sollentuna	Saltsjö-Boo	Total
Single-family homes	423	543	966
Condos	597	531	1128
Rentals	512	537	1049
Total	1532	1611	**3143**

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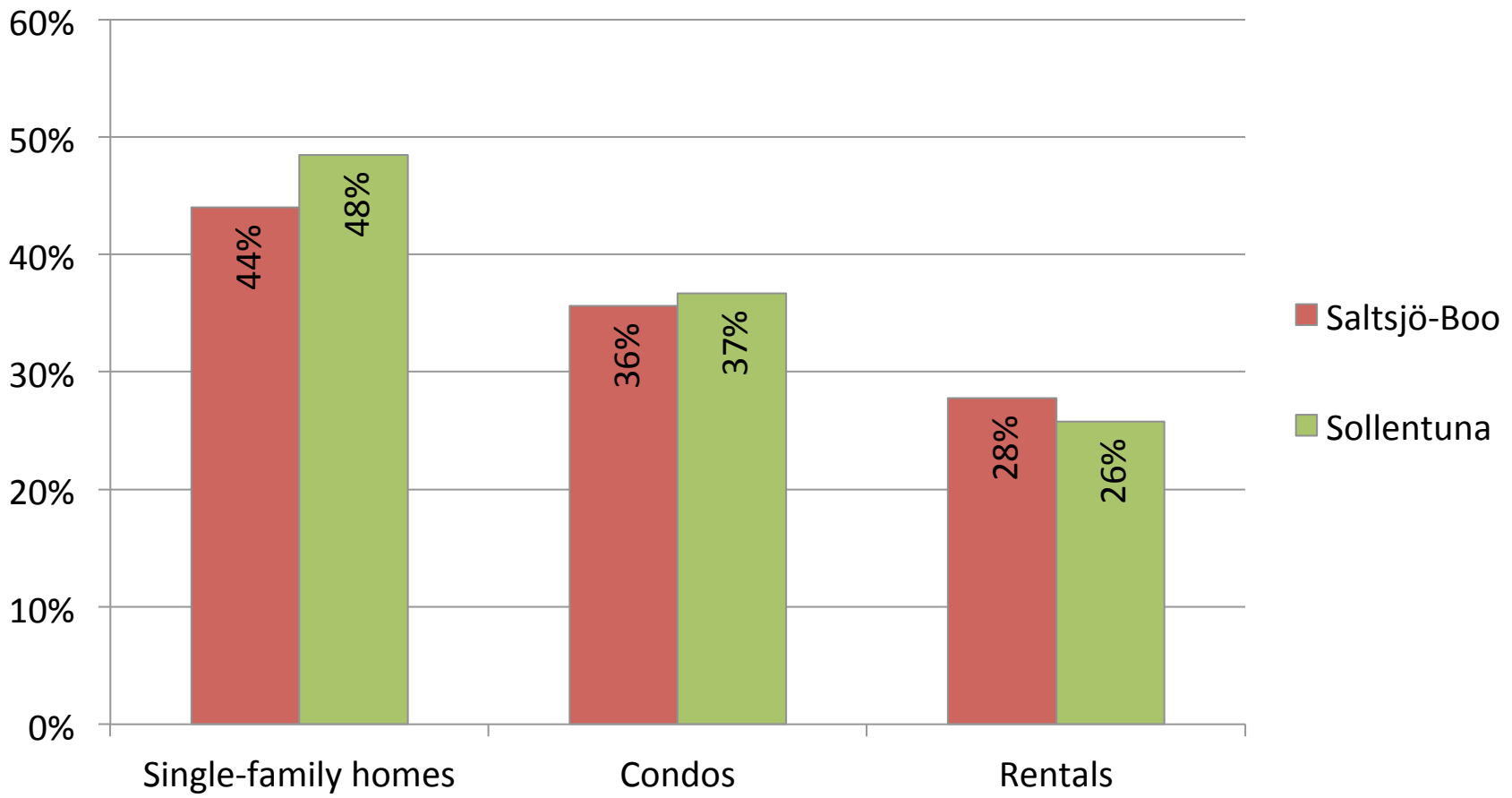
Response rate



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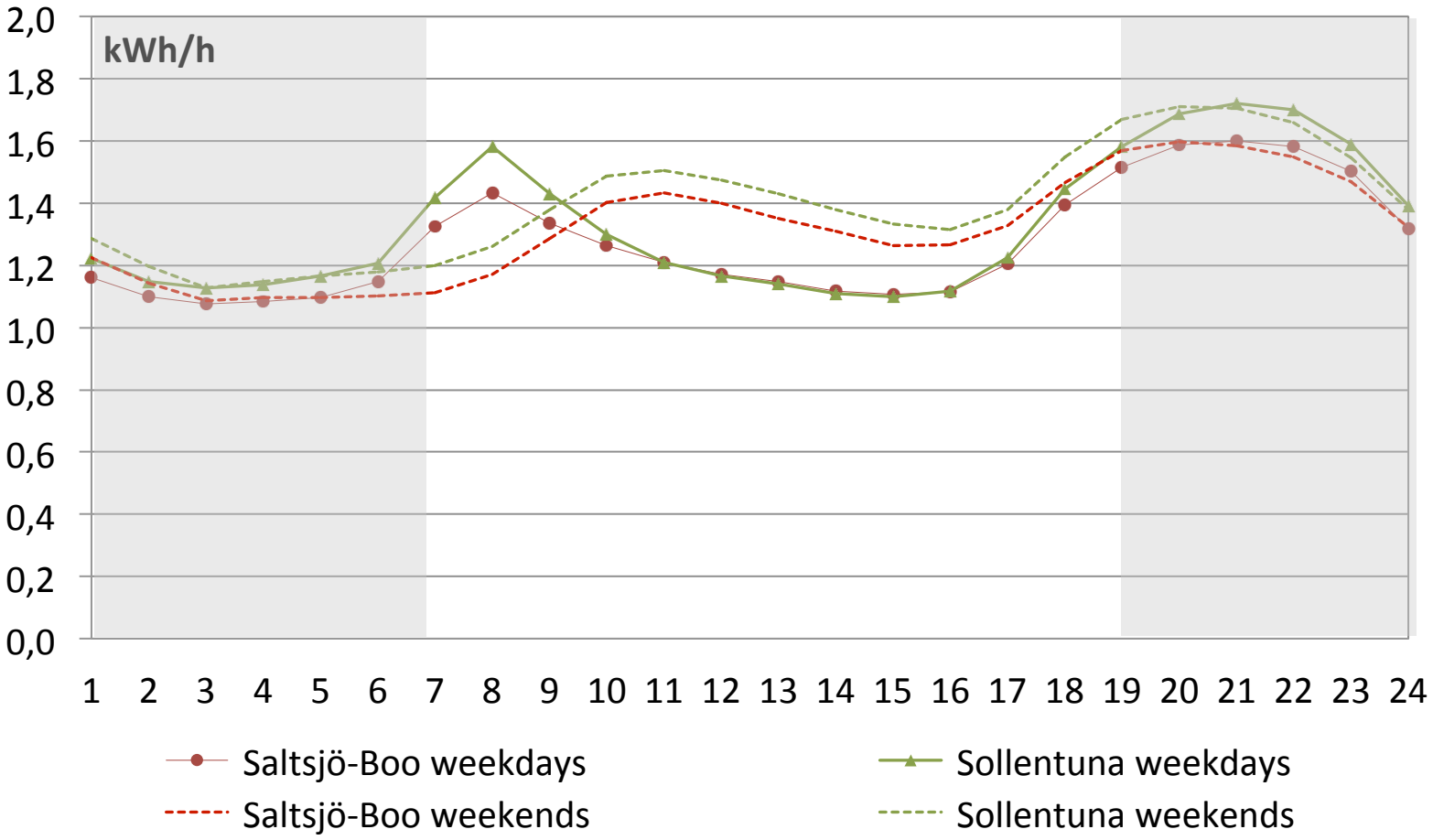
Load curves of single-family homes



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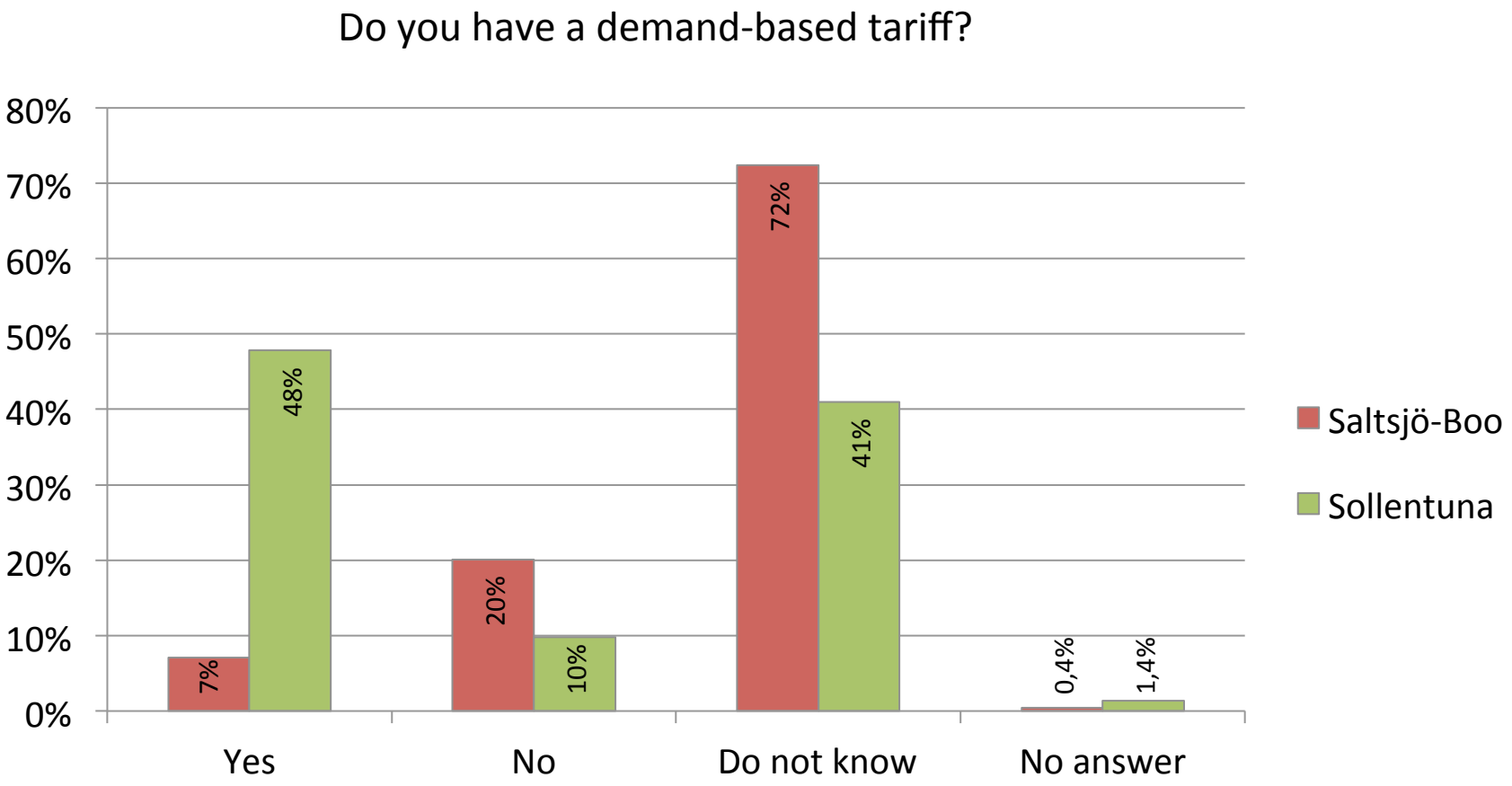
Knowledge of the tariff in single-family homes



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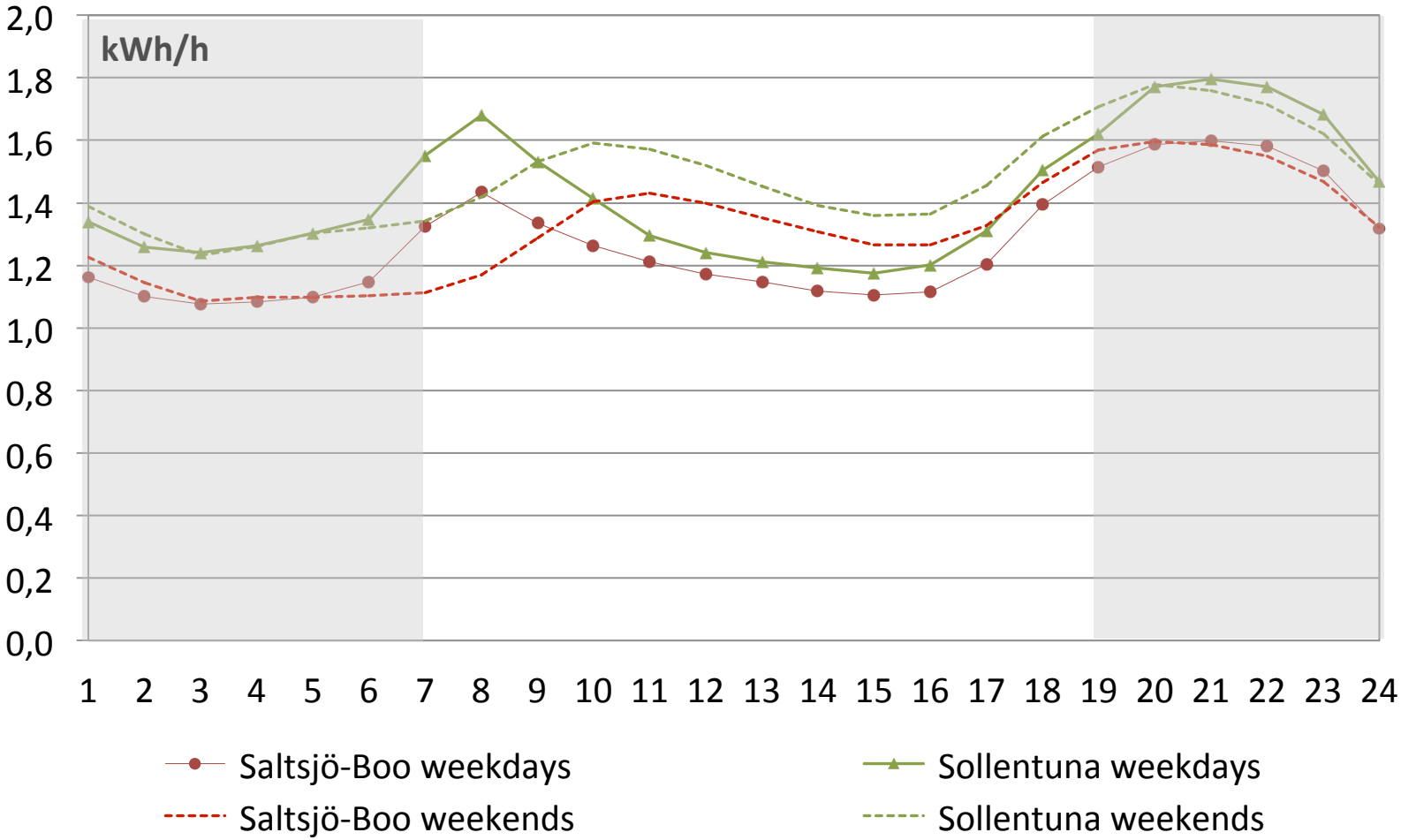
Load curves of single-family homes

including only those who have knowledge of the tariff



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Results of demand response estimations

- shift from peak to off-peak hours by **2,3** and **1,2 %** among single-family home owners in the summer and winter season
- shift from peak to off-peak hours by **2,9** and **2,0 %** among those single-family home owners who had knowledge of the demand-based tariff in the same period
- fairly marginal response, which is more or less restricted to single-family home owners
- considerable variance in the data set

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Energy Efficiency Gap

People are affected by economic incentives, but not as much as expected and they also have potential drawbacks

Behavioral motivations

- Consequences (economic and other),
  - Humans are **social creatures**,
    - Social norms (expectations),
      - Moral issues.
    - Perceived capabilities.

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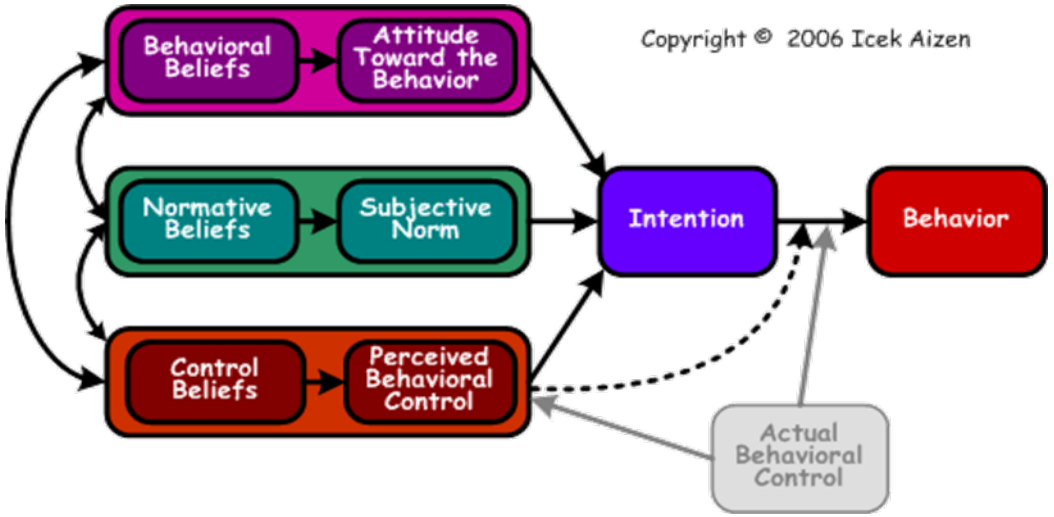
Theory of Planned Behavior

http://people.umass.edu/aizen/



- **Attitudes**: Consequences of the behavior,
- **Subjective norm**: Social expectations (“pressure”),
- **<u>Perceived</u> control**: Control of the behavior.

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Expectancy-value based Integration of Goals and Beliefs

Goal

Decreased cost for electricity in the household is important:

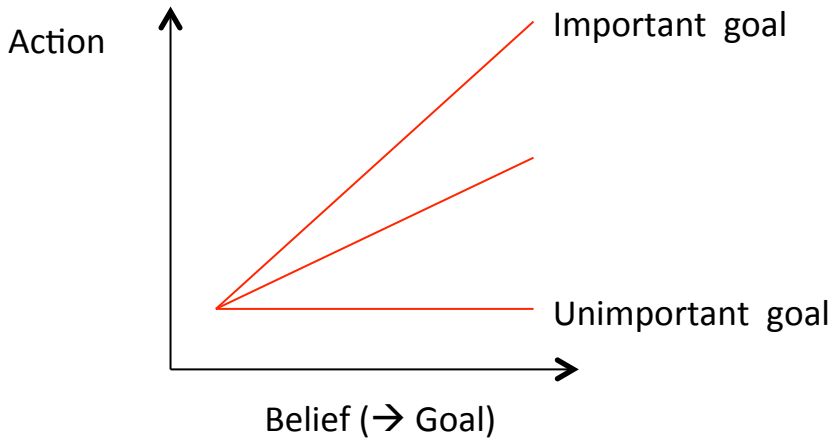
1	2	3	4	5	6	7
Not at all						Very much

Belief

Moving use of eletricity to off-peak hours will decrease the electricity cost:

1	2	3	4	5	6	7
Not at all						Very much

$$Action = Goal \times Belief$$



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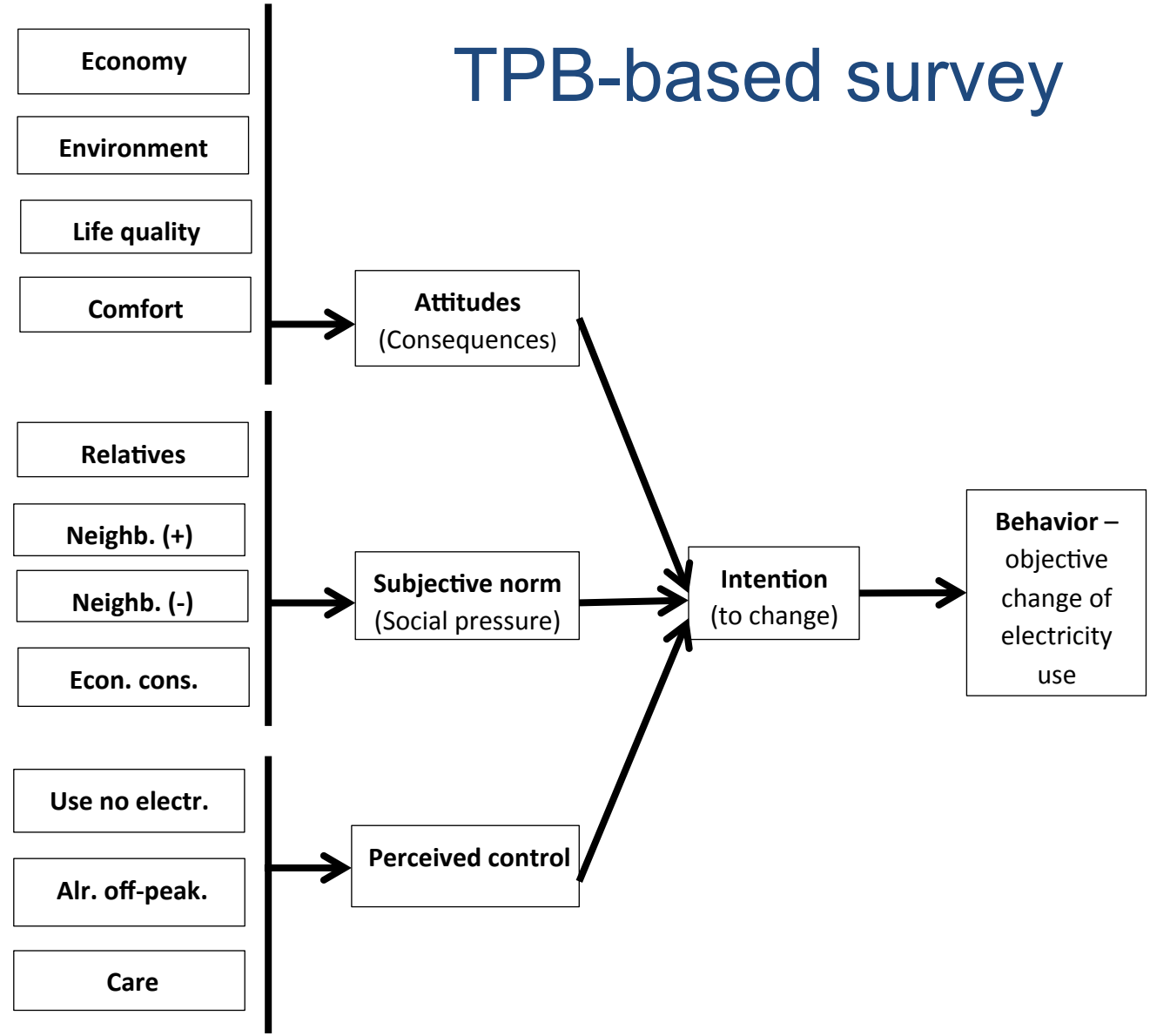
TPB-based survey

Concrete motivators identified in pilot study



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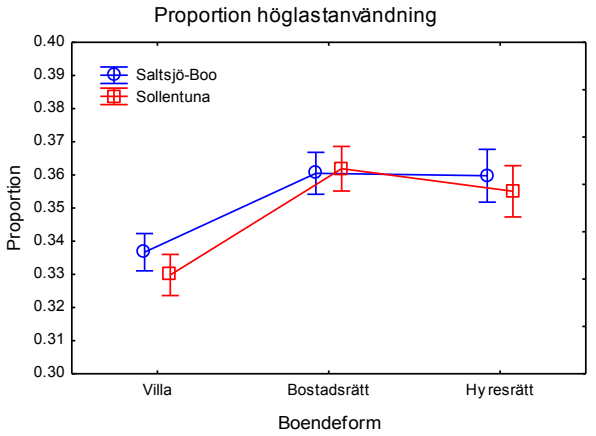
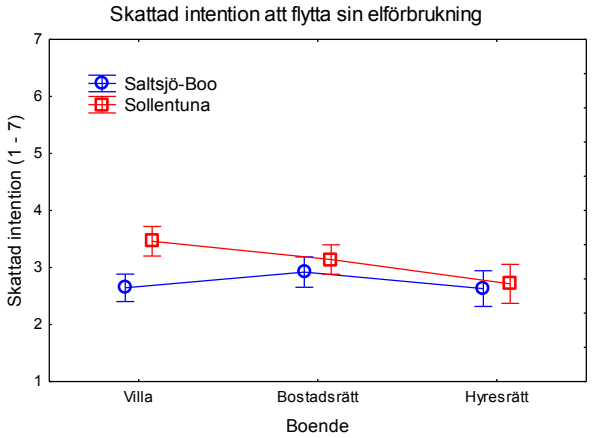
Results (Survey Responders)

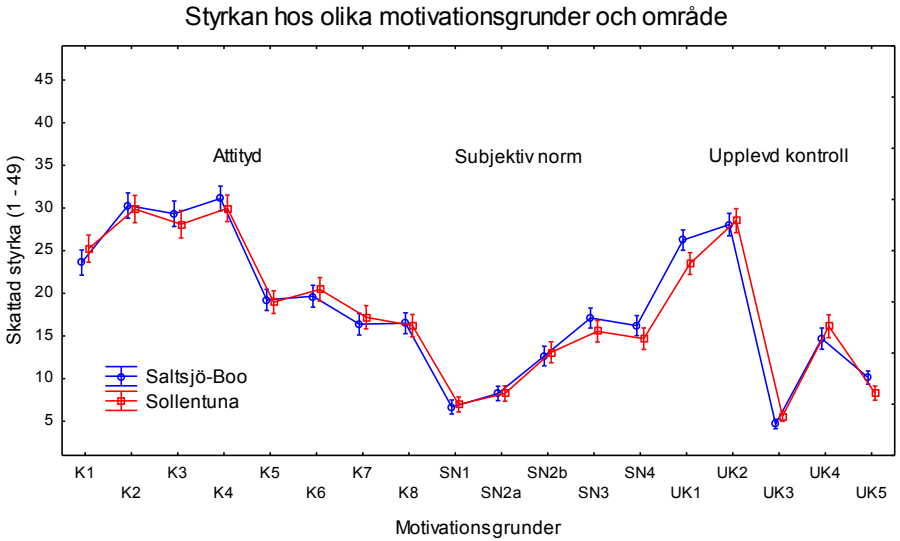
- No reliable effect on behavior (electricity use) of economic incentives,



- Statistically reliable effect on the intention to change the behavior.



Self-rated Motivation to Change



- Saving money was one strong motivation,
- Environmental benefits stronger motivators,
- Subjective norm low (self-assessed) motivator,
- The main hindering factors were:
  - We use (virtually) no electricity at all,
  - Already use all electricity in the evening/weekends

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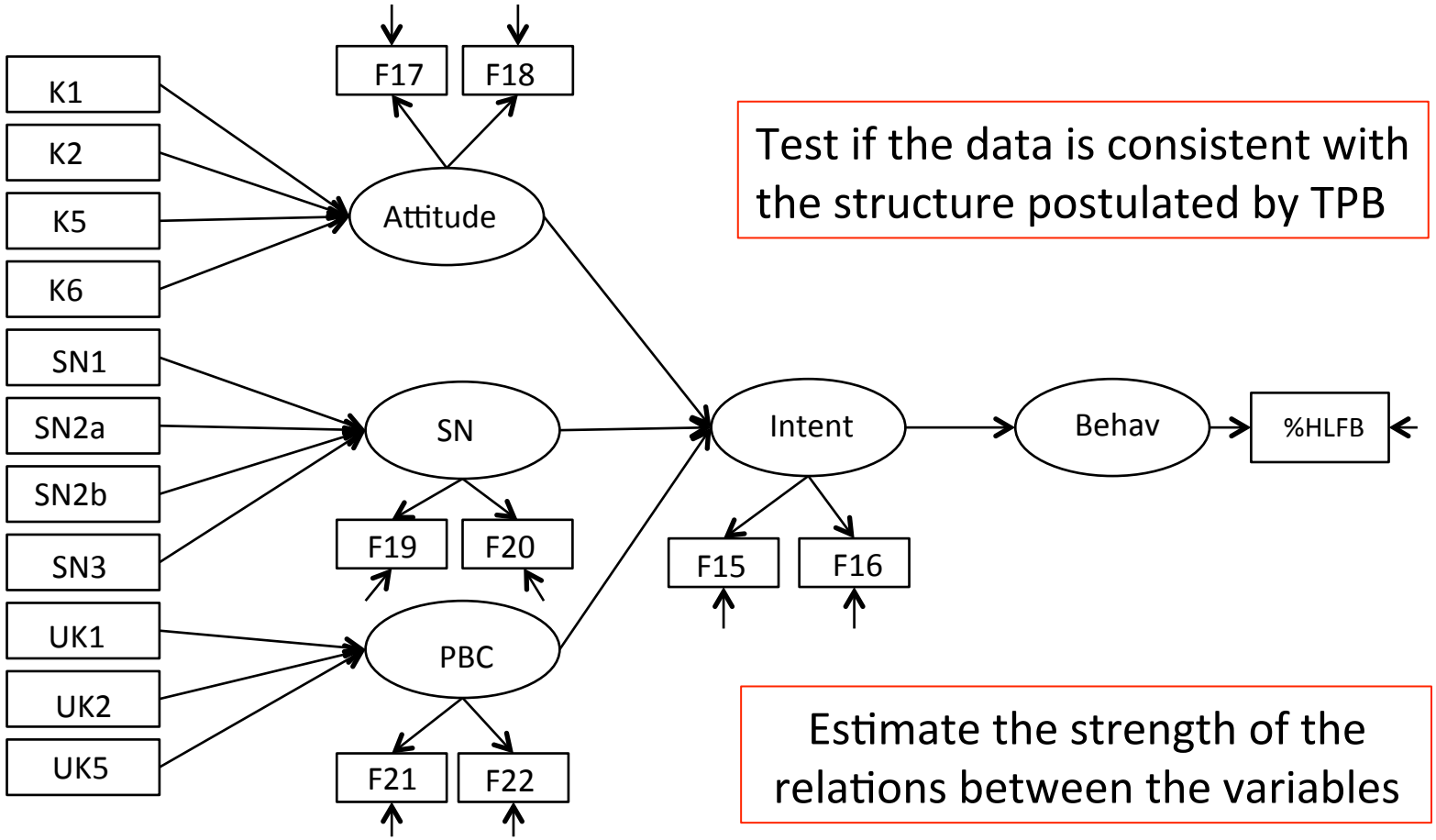
Test of the TPB-model with Structural Equation Modelling (LISREL)



Test if the data is consistent with the structure postulated by TPB

Estimate the strength of the relations between the variables

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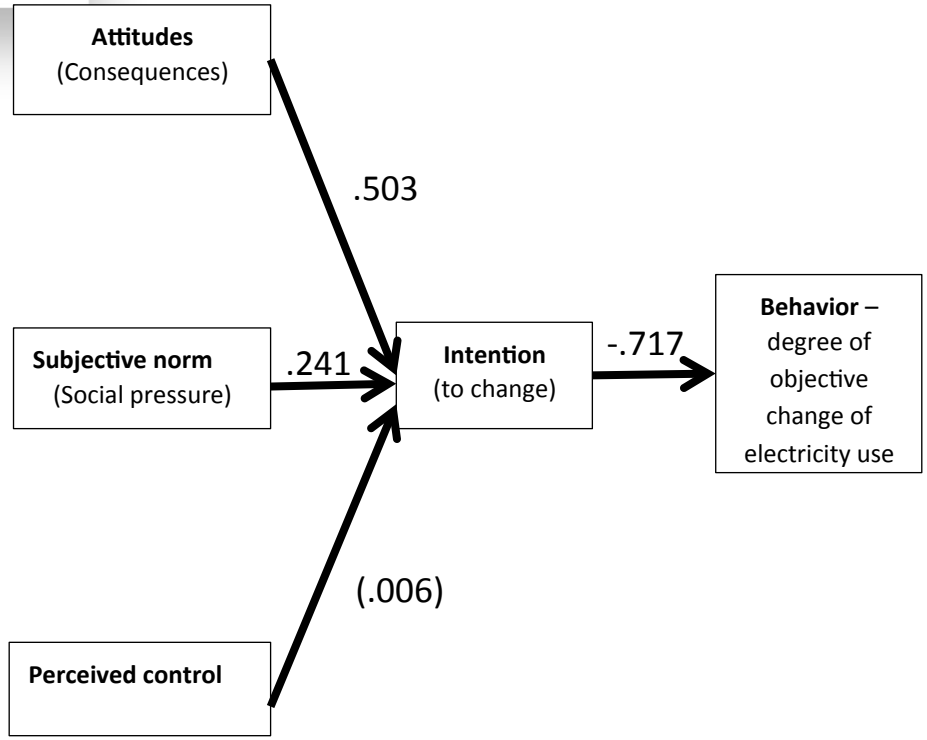
Model Application

The analysis was performed in two steps:

1. The model is tested with whole data set.
2. Separately for Sollentuna and Saltsjö-Boo.

Goodness-of-Fit Statistics (whole data set)	
Chi-Square (DF)	193.506 (109)
Root Mean Square Error of Approximation (RMSEA)	0.0594
Goodness of Fit Index (GFI)	0.950
Comparative Fit Index (CFI)	0.959
Normed Fit Index (NFI)	0.944

Results for Whole Sample



No apparent effect of perceived behavioral control

Effect of perceived behavioral control, but interacts with attitude (a hindering factor is operative only if you have a positive attitude to the behavior in the first place).

	Int	Att	SN	Pbc	R^2
Behav	- 0.717 (0.149) -4.797	-	-	-	0.0424
Int		0.503 (0.0623) 8.079	0.241 (0.051) 4.752	0.0062 (0.0365) 0.169	0.750

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Real Predictors of Off-Peak Use

	K1	K2	K5	K6	SN1	SN2A	SN2B	SN3	UK1	UK2	UK5	R^2
Att	0.142 (0.0162) 8.187	-0.0468 (0.0135) -3.466	0.107 (0.022) 4.865	- 0.188 (0.0243) -7.717	-	-	-	-	-	-	-	0.783
SN	-	-	-	-	-0.181 (0.0538) -3.364	0.526 (0.0924) 5.692	- 0.262 (0.0474) -5.513	-0.00358 (0.0162) 0.221	-	-	-	0.893
Pbc	-	-	-	-	-	-	-	-	- 0.00789 (0.00768) -1.027	0.108 (0.00866) 12.463	- 0.149 (0.0148) -10.083	0.379
Behav	- 0.0514 (0.014) -3.795	0.0169 (0.00628) 2.686	- 0.0387 (0.0124) -3.124	0.0677 (0.0183) 3.696	0.0313 (0.0129) 2.427	- 0.0909 (0.0301) -3.023	0.0452 (0.0151) 2.992	0.000620 (0.00282) 0.220	0.000 (0.0002) 0.166	- 0.00048 (0.00283) -0.169	0.000659 (0.00390) 0.169	0.0275

- Economic incentives significantly predicts off-peak use,
- Environmental concerns significantly predicts off-peak use,
- Beliefs about comfort significantly predicts off-peak use,
- Subjective norm significantly predicts off-peak use,
- Perceived behavioral control interacts with attitude.

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Results for the two Areas Separately

	Int	Att	SN	Pbc	R^2
Saltsjö-Boo					
Behav	- 0.430 (0.230) -1.866	-	-	-	0.0112
Int		0.446 (0.0428) 10.427	0.234 (0.0446) 5.253	0.109 (0.0271) 4.016	0.640
Sollentuna					
Behav	- 0.958 (0.217) -4.411				0.0687
Int		0.548 (0.0477) 11.479	0.262 (0.0491) 5.327	0.0210 (0.0290) 0.725	0.726

The relationship between intention an behavior stronger in Sollentuna

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Saltsjö-Boo

	K1	K2	K5	K6	SN1	SN2A	SN2B	SN3	UK1	UK2	UK5	R^2
Att	0.0287 (0.0055) 5.272	0.0300 (0.0054) 5.544	- 0.0185 (0.0093) -1.998	- 0.0276 (0.0091) -3.029	-	-	-	-	-	-	-	0.454
SN	-	-	-	-	0.0289 (0.0104) 2.778	0.0647 (0.0126) 5.147	- 0.0222 (0.0060) -3.694	0.0170 (0.0058) 2.945	-	-	-	0.385
Pbc	-	-	-	-	-	-	-	-	0.00402 (0.0075) 0.538	0.0441 (0.0068) 6.458	- 0.0281 (0.0087) -3.229	0.149
Behav	- 0.0055 (0.0031) -1.757	- 0.0058 (0.0033) -1.767	0.00355 (0.0026) 1.363	0.00529 (0.0033) 1.588	- 0.0029 (0.0019) -1.505	- 0.0065 (0.0039) -1.692	0.00223 (0.0014) 1.612	- 0.0017 (0.00112) -1.530	-0.00021 (0.00037) -0.513	- 0.0021 (0.0013) -1.657	0.00131 (0.00087) 1.514	0.0365

The effect of economic incentives is not significant in Saltsjö-Boo

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Sollentuna

	K1	K2	K5	K6	SN1	SN2A	SN2B	SN3	UK1	UK2	UK5	R^2
Att	0.0295 (0.00585) 5.053	0.0436 (0.00603) 7.223	- 0.0212 (0.00737) -2.872	- 0.0237 (0.00708) -3.346	-	-	-	-	-	-	-	0.524
SN	-	-	-	-	0.0344 (0.0092) 3.727	0.0346 (0.0103) 3.374	- 0.0122 (0.0053) -2.291	0.0261 (0.0060) 4.372	-	-	-	0.377
Pbc	-	-	-	-	-	-	-	-	- 0.0147 (0.0080) -1.837	0.0387 (0.0074) 5.243	- 0.0220 (0.0171) -1.292	0.106
Behav	- 0.0155 (0.0046) -3.350	- 0.0229 (0.00601) -3.806	0.0111 (0.00459) 2.418	0.0124 (0.00464) 2.679	- 0.0086 (0.0033) -2.616	- 0.0087 (0.0035) -2.485	0.00306 (0.0016) 1.942	- 0.0065 (0.0023) -2.809	0.00030 (0.00044) 0.668	- 0.00078 (0.0011) -0.710	0.00044 (0.00071) 0.627	0.0278

The effect of economic incentives on Behavior is significant in Sollentuna, but not in Saltsjö-Boo. Signs of “spill over effects”: all motivators are better predictors of behavior in Sollentuna.

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Conclusions

- **No or small differences in patterns of electricity use between Sollentuna (tariff) and Saltsjö-Boo (no tariff)**.
- **Effects at the psychological level:**
  - Stronger intention to shift the load in Sollentuna,
  - Stronger correlation between intention to shift and behavior.
  - "**Spill over**": stronger correlation both between economic incentives and environmental concerns and behavior in Sollentuna.
- **TPB was successful in predicting this behavior:**
  - Attitudes,
  - Subjective norm,
  - Perceived control x attitude (interaction).
- **Concrete motivators**:
  - Economic incentives,
  - Environmental concerns,
  - Perceived control (already using their electricity in evenings/weekends).

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Model Specification

- Model employed in the current analysis is a special type of Structural equation model, and it is so called Multiple Indicators Multiple Causes (MIMIC) model. The model is presented in the matrix form as following:

$$y = \Lambda_y \eta + \varepsilon \ ,$$

$$\eta = \Gamma x + \varsigma \ .$$

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Model Specification

- where $\boldsymbol{y}$ is a vector includes all the measurement, i.e., F15, F16, F17, F18, F19, F20, F21, F22 and %HLfb. Vector $\boldsymbol{x}$ includes all the independent variables, namely, K1, K2, K5 K6, SN1, SN2a, SN2b, SN3, UK1, UK2, and UK5. $\boldsymbol{\eta}$ is the vector with all the latent constructs, i.e., Behavior (Behav), Intention (Int), Attitude (Att), Social Norm (SN), and Perceived Behavior Control (Pbc). Λ_y is the factor loading matrix, Γ is the coefficient matrix. $\boldsymbol{\varepsilon}$ and ζ are the errors terms.

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Results for Whole Sample

- In order to estimate the full SEM model we first tested the measurement model, namely, testing validity and reliability of measures (indicators) of latent variables. The results has shown that all the measurements are highly reliable with high validation coefficients.

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Results for Whole Sample

- The results from the full TPB model with both areas included. The measurement equations show that all the indicators are valid (Table 1). The structural equation reveals that Intention has a negative significant impact on behavior. Effect of Pbc on intention is not significant (Table 2). The goodness of fit indices shows that the model fits the data well. Table 3 gives the reduced form of structural equations. Table 4 is for the model fit statistics.

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Results for Whole Sample

- Table 1. Measurement Equations. The numbers in table are parameter estimates, standard errors in parentheses and T-values.

	Int	Att	SN	Pbc	R^2
F15	1.506 (0.095) 15.815				0.791
F16	1.000				0.377
F17		0.964 (0.027) 36.021			0.798
F18		1.000			0.810
F19			0.974 (0.046) 21.704		0.597
F20			1.000		0.653
F21				1.011 (0.037) 27.242	0.861
F22				1.000	0.853

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Results for Whole Sample

- Table 4. Model fits indices.

Goodness-of-Fit Statistics	
Chi-Square (DF)	193.506 (109)
Root Mean Square Error of Approximation (RMSEA)	0.0594
Goodness of Fit Index (GFI)	0.950
Comparative Fit Index (CFI)	0.959
Normed Fit Index (NFI)	0.944

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Results for Whole Sample -Interaction Effects

- As it is seen in Table 2, the effect of Pbc on intention was not significant as theory indicated. We suspect that the Pbc functions vis Attitude, in other words, there is an interaction effect between Pbc and Attitude on Intention.
- To test this hypothesis we isolated model including only psychological variables and introduced product variable AttPbc. The coefficient of the product variable in indicates the significance of interaction effect. The Path diagram of the model with interaction effect is shown in next slide.

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Results for Whole Sample -Interaction Effects

- The interaction effect has been tested using three different methods, i.e., Subgroup analysis, Two stage least squares, and Factor scores analysis. All three methods gave similar results. Table 5 show the results.

	Att	SN	Pbc	AttPbc	R^2
Int	0.769 (0.0363) 21.204	0.339 (0.0406) 8.342	0.0182 (0.0278) 0.654	0.0300 (0.0117) 2.574	0.714

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Results for two areas separately

- The results for both areas as separate group will be shown in this document. The analysis is done by assuming the measurement model invariant over the groups. But the structural models are different.