Activities and Findings

Research and Education Activities:

a) Bayesian Model Synthesis

(Steven MacEachern and Mario Peruggia, with student Qingzhao Yu)

We address the problem of how to conduct a legitimate Bayesian analysis while still allowing one to develop likelihood and prior by exploring the data. The methodology is based on a principle of data splitting, whereby several analysts examine portions of a data set, with each producing a Bayesian summary. The individual analyses are synthesized by means of formal Bayesian methods, implemented with the aid of Monte Carlo simulation. A theoretical development describes performance of data splitting for an abstraction of individual data analyses; success of the method is demonstrated empirically through application of the methodology to several data sets.

b) Advertising response modelling

(Greg Allenby with student Sandeep Rao)

An associative network representation of consumer memory involving motivating Conditions,(i.e., needs, product attributes and considered Brands) has been validated using experimental data and modeled using hierarchical Bayesian methods. A universally agreed upon goal of advertising may be conceptualized as an attempt to change this network such that a specific brand becomes part of the consideration set. Substantively, the first layer of the network represents which activity-related concerns and interests matter to the consumer. Depending on the concerns and interests and a consumer's network structure, i.e. beliefs about which attributes help address specific concerns and interests, certain product attributes become important. Given which attributes are deemed important, a consumer's brand beliefs, modeled as links between attributes and brands in the network, determine which brands are selected into the consideration set. Given a specific network structure we were able to recover concerns and interests as latent variables as well as an activation threshold using an MCMC algorithm. We are in the process of investigating the effect of advertising on the link structure and threshold parameters in consumer specific networks in an experimental setting.

c) Confidence judgments: an integrated model of choice and response time with application to conjoint analysis

(Thomas Otter, Greg Allenby and Trisha Van Zandt)

Response times and discrete choices are jointly modeled using a time-varying Poisson process where choice alternatives generate signals in the respondent's mind. A choice is made when a sufficient number of signals are generated, and the response time corresponds to the time taken for the fastest process to reach a threshold. The allocation of limited cognitive resources in evaluating multiple alternatives in a choice set alters the rate at which signals are generated for any one alternative. The integrated model, marginally, nests the standard logit model when the threshold is constrained to one signal. We show that i) the estimated model has threshold values different from one for the majority of respondents; ii) response times are informative about respondents' preferences, diligence, and cognitive capacity allocated to the choice task; iii) limited cognitive resources increase response times as a function of choice set characteristics; iv)respondents exhibit learning effects associated with quicker responses later in the

conjoint task; v) holdout predictions for the proposed model improve relative to the logit model; and vi) our integrated model compares well to a purely conditional approach which assumes that response times are exogenously determined.

d) Theoretical aspects of the Poisson race model
(Steven MacEachern, Angela Dean, Thomas Otter, and student Shiling Ruan)
We have considered the use of the Poisson race model for modeling consumer choice data. Under this model, a counter records information and preferences for an option as a 'hit' to a counter. Each option has its own, independent counter. The consumer's choice is the option whose counter first reaches its threshold value. We have considered the impact of different thresholds for each option and have looked at a variety of formulas that describe the probability of selecting an option. We have constructed a novel set of models that allow us to distinguish between utility dominance and dominance on all aspects of an option. We have collected consumer choice data and have fit the new models to the data. The new models perform substantially better than models in current use.

e) Optimal experimental designs for hyperparameter estimation in hierarchical linear models
(Angela Dean, Greg Allenby and student Qing Liu)
Understanding the contexts in which consumers are sensitive to offers, and variables such as price, is an important aspect of merchandising, selling and promotion. In this research, we have proposed efficient methods of learning about contextual factors that influence consumer preference and sensitivities within the context of a hierarchical Bayes model. We have developed a new criterion for optimal experimental designs for estimating the hyperparameters in such a model. We have shown that optimal designs under this criterion are not always the balanced orthogonal designs that are best for linear models. We have derived optimal factorial design structures in some specific settings.

f) Analysis of Q-sort profiles for segmenting a consumer base.
(Michael Browne and student Longjuan Liang)
An existing model for the analysis of Q-sort profiles that provides a structure for an inter-person correlation matrix over Q-sort items has been reformulated as a model for the actual data. The controversial inter-person correlation matrix has been eliminated conceptually and computationally. Estimates are obtained using the singular value decomposition and new two sided orthogonal and oblique rotation algorithms have been developed to yield interpretable person loadings and typical profiles. The preparation of a computer program has been completed. A joint project with Kenneth Demarree (OSU, Department of Psychology) and Derek Rucker (Kellogg School of Business) on the practical use of the component analysis of Q-sort profiles for distinguishing affective and cognitive bases of attitudes is in progress.

g) Determinants of Trademark Dilution
(Greg Allenby)
A hierarchical Bayes associative network model for brand information is developed and tested to measure the extent of harm from trademark dilution. In the proposed model, category activation thresholds are modeled in terms of brand/category familiarity,

activation flows are modeled in terms of relative category knowledge, and consumer confusion and its correlates are used to capture the asymmetric fan effects on retrieval probabilities for first and second users.

h) Models for Rankings
(Michael Fligner and Steven MacEachern)
Ranked set sampling is a technique that relies on the ability of an evaluator to rank units in a head-to-head fashion. The ranking produces a covariate which is then available for use in further analyses. The problem is quite similar to consumer choice experiments, although ranking is based on an assessment of features of the units rather than on an assessment of the utility of a unit. We have developed a collection of models that allow us to connect underlying true values for units to the perceived values used for ranking. The models allow us to capture desirable properties of rankings such as stochastic ordering of true values by rank, monotone likelihood ratios, etc, while remaining flexible enough to retain features that we wish to retain, such as allowing ties in rankings and allowing nonparametric distributions (i.e., distributions that lie outside typical parametric families). With the models established, the work has progressed to fitting Bayesian versions of the models with Markov chain Monte Carlo techniques.

i) A Model of State Dependence based on Auto- and Cross-correlated Exponential Processes
(Thomas Otter, Mario Peruggia, and Xiuyun Zhang)
We investigate the applicability of epidemic-type point process models that have been used to describe various kinds of time-to-event data to modeling state dependence in consumer purchase histories. We extend existing joint models of brand choice and purchase timing to include cross correlation. The decomposition of time and brand specific rates into a base rate, the contribution of past purchases of the same brand (autocorrelation), and that of past purchases of other brands (cross-correlation) is expected to sharpen the understanding of how the marketing mix variables price, display, feature and product affect consumers' actions. We have developed MCMC code to fit the hierarchical Bayes model to a set of household panel data.

j) Nonparametric Item Response Theory
(Michael Browne, Steven MacEachern and student Longjuan Liang)
A class of item response functions that can approximate any specified item response function arbitrarily closely by increasing the number of parameters has been developed. Each item response function in this class is the composition of a logistic item response function and a monotonic polynomial of a prespecified order. A method for obtaining estimates of item parameters and are person abilities under the assumption of a normal ability distribution have been developed. The advantages of this approach is that item response functions for different items can have substantially different shapes. It also facilitates the incorporation of an option for allowing nonmonotonic item response functions. A comparison of the method under development with Bayesian methods will be undertaken. A computer program has been written and the method has been tested both on real data sets and in random sampling experiments. The new procedure has been compared with standard item response methods, a nonparametric Bayesian method and a

nonparametic data smoothing procedure. Results have been encouraging both in terms of flexibility of the item response curves and the new procedure has been demonstrated to be sufficiently rapid for routine use with possibly large data sets.

k) Combinatorial and geometric equivalence of designs for fractional factorial experiments
(Angela Dean and students Tena Katsaounis, Cheryl Dingus)
Equivalent factorial designs have identical statistical properties for estimation of factorial contrasts and for model fitting. Non-equivalent designs, however, may have the same statistical properties under one particular model but different properties under a different model. We have investigated a large number of methods, some of which are new, for the determination of combinatorial and geometric equivalence and non-equivalence of experimental designs. Combinatorial equivalence is relevant for studies where the factor levels (attributes) have no inherent ordering, such as brand, while geometric equivalence is relevant when levels are ordered, such as price.

l) Nonparametric Bayesian item response theory
(Steven MacEachern and student Kristin Duncan)
The standard item response theory models are extended through development of nonparametric Bayesian versions of the models. The new models are based on the Dirichlet process. They allow for an arbitrary distribution of abilities in a population, and also allow the item response curves to be monotonic, but otherwise arbitrary. The new models are shown to detect departures from the traditional models and result in improved estimates of abilities.

m) Incorporation of additional psychological tests in an existing circumplex representation of personality characteristics.
(Michael Browne and student Longjuan Liang)
Some types of personality characteristics may be arranged in a circular order with characteristics that are close to each other on the circumference of a circle having high positive correlation coefficients and those pairs that are at opposite sides of the circle having substantial negative correlation coefficients. This circular representation of a pattern of interrelationships between personality characteristics is known as a circumplex. It is frequently of interest to project additional measures of a personality characteristic onto an existing circumplex. A method for doing this has been developed. The correlation coefficients between an additional measure and the tests in the existing circumplex are employed to locate the new characteristic on the circumference of the existing circumplex and assess its communality with the existing tests. A computer program has been written and the method has been successfully applied in a practical situation.

n) Judgement post-stratification for designed experiments
(Steven MacEachern and student Juan Du)
Judgment post-stratification is a technique closely allied to ranked set sampling. It relies on subjective judgment (or coarse modeling) to create additional covariates for an analysis. These covariates are then exploited to improve inference. Asymptotic theory is developed. The methodology is applied to designed experiments, with judgments made

either before treatment is applied to the experimental units, or on the basis of pre-experimental information by a blinded judge, after the experiment. Making use of these judgments reduces the conditional (on the realized randomization) bias of estimators, increases the power of hypothesis tests, and shortens confidence intervals.

o) Robust-likelihood and CUSUM charts
(Steven MacEachern and students Youlan Rao, Chunjie Wu)
The CUSUM chart, among the most popular methods for monitoring a manufacturing process, is an extension of Wald's sequential probability ratio test to account for a dynamic environment. Traditional CUSUM charts do not work well for outlier prone distributions. Motivated by censoring, a robust likelihood is developed which results in a monotone robust likelihood ratio. The robust likelihood is truly a likelihood, and so tests based on it inherit properties similar to those of uniformly most powerful tests. A robust version of the CUSUM chart is constructed, its theoretical properties are examined, and the chart is shown to perform well.

p) Order restricted randomized design
(Omer Ozturk and Steven MacEachern)
Order restricted randomized designs provide a means of incorporating subjective or coarse information on sets of experimental units at the design stage. The information is exploited by placing appropriate restrictions on the assignment of treatments to experimental units. The information is also formally incorporated into the model used to analyze the data. The resulting designs are more efficient than designs which ignore the information.

q) Efficient repeated measurement designs in the presence of interactions between direct and carry-over treatment effects
(DongKwon Park, Mausumi Bose, William Notz, Angela Dean)
Repeated measurement designs are used for crossover experiments in which a number of different stimuli are applied in succession to each of n subjects over a given number of time periods. Such designs are widely used in many areas including psychological experimentation. In addition to the direct effect of a stimulus in the period of application, there is also the possible presence of a carry-over effect of a stimulus from one or more previous periods. Typical work in this area assumes that the carryover effect from a given stimulus will remain the same no matter which stimulus succeeds it. In this work, we use a more general model that allows interactions between the direct and carryover effects of the stimuli. We show that a particular type of strongly balanced repeated measurement design, uniform on the periods, is highly efficient for estimating the parameters in the model.

r) Minimally informative nonparametric Bayesian analysis
(Steven MacEachern and students Christopher Bush, Juhee Lee)
An outstanding problem in the area of nonparametric Bayesian methods is how to create a prior distribution that leads to a ``noninformative'' analysis. We develop a means to do this, constructing limits of Dirichlet processes in which the base measure tends to an appropriate (improper) measure. Both the dispersion of the base measure and the mass of

the base measure are adjusted in order to ensure that posterior inference does not become degenerate. The methodology is applied to analysis of variance.

s) Psychological processes underlying violations of Luce's choice axioms: Critical evaluation and comparison of process models of choice
(Thomas Otter, Steven MacEachern, Greg Allenby, and student Shiling Ruan)
Violations of Luce's choice axioms such as similarity, compromise and attraction effects have been widely documented in experimental behavioral research. However, the majority of applications of choice models in marketing still employ random utility models the probabilities implied by which are essentially in line with Luce's choice axioms. In contrast, researchers in mathematical psychology have developed a variety of mathematical and algorithmic representations of processes underlying choice that structurally motivate departures from Luce's axioms from elementary assumptions.

t) An empirical Bayesian approach to misspecified covariance structures
(Michael Browne and student Hao Wu)
Because models typically do not fit exactly to the population in real life applications, the classical approach to hypothesis testing suffers from the fact that the null hypothesis will, in practice, be rejected whenever the sample is very large. To avoid this problem various measures of model misfit have been developed to replace tests of point hypotheses in the analysis of covariance structures. These measures of misfit, however, are post-hoc modifications of the likelihood ratio test statistic for a perfectly fitting model. To avoid this self-contradictory modus operandi, we are developing an empirical Bayesian approach which directly addresses the issue that the model does not fit the population covariance matrix. In this approach, we model two different aspects of discrepancy between the observed sample and the structural model. In addition to the sampling errors that result in a difference between the sample and the population, systematic errors that give rise to the discrepancy between the population and the model are modeled by a prior distribution on the population covariance matrix. An additional parameter denoting the dispersion of the prior distribution is considered as a measure of misspecification and estimated together with the covariance structure.

u) Nonparametric Bayesian models to replace weighted least squares
(Steven MacEachern and student Zhen Wang)
There are two primary motivations for the weights in weighted least squares. The first is that the errors follow a scale family; the second is that errors arise as a convolution of i.i.d. errors at a more refined scale. When the errors are normally distributed, the motivation for the model is irrelevant. However, when the errors are not normally distributed, the motivations lead to different models. The two models can be distinguished on the basis of data. The shape of the error distribution in the scale setting is completely invariant to weight. On the other hand, the shape of the error distribution in the convolution setting moves towards that of the normal distribution as the amount of convolution increases. Techniques are developed for identifying the model as scale, convolution or between the two. A family of models that includes scale and convolution models as endpoints is developed, and computational strategies are developed for fitting the family of models.

v) Models for heterogeneity of scale usage in surveys
(Greg Allenby, Peter Craigmile, Chris Hans, Steven MacEachern, Xinyi Xu, and student Juhee Lee)
When presented with a questionnaire, different respondents react to the questions in different fashions. Some use the full response scale, and some use only a small portion of the response scale, perhaps only the top end or the bottom end. We develop hierarchical Bayesian models that allow calibration of the individual's use of the survey scale. The models allow for individual and group-level heterogeneity. We also develop effective computational strategies for working with the models.

w) Methods of screening for important factors
(Angela Dean, David Woods, Susan Lewis, Anna Vine, and student Danel Draguljic)
Experimental studies, whether for psychological experiments or marketing, may involve a large number of factors (stimuli, attributes) that may drive the response. We are investigating two methods supersaturated designs and group screening) that have been suggested as methodologies for screening out unimportant variables. We are also comparing frequentist and Bayesian analysis methods in this setting.

x) Bayesian Analysis of Hierarchical Effects
Jeff D. Brazell, Greg M. Allenby and students Sandeep Chandukala, Jeffrey Dotson,)
The idea of hierarchical, sequential, or intermediate effects has long been posited in textbooks and academic literature. Hierarchical effects occur when relationships among variables are mediated through other variables. Despite the attractive theoretical properties of these models, their practical existence has been difficult to show in empirical studies. We propose an approach to studying hierarchical effects using sets of conditional relationships among affected variables while allowing for heterogeneous response segments, and using Bayesian variable selection to deal with the high dimensional parameter space often encountered in applied empirical studies. Cross-sectional data from a national brand-tracking study is used to illustrate our model, where we find empirical support for a hierarchical relationship among media recall, brand beliefs, and intended actions. We find these effects to be insignificant when measured with standard models and aggregate analyses. The proposed model is useful for understanding the influence of variables that lead to intermediate as opposed to direct effects on brand choice.

y) Studying the Level-Effect in Conjoint Analysis: An Application of Efficient Experimental Designs for Hyper-parameter Estimation
Angela Dean, David Bakken, Greg M. Allenby and student Qing Liu)
Research in marketing, and business in general, involves understanding when effect-sizes are expected to be large and when they are expected to be small. An example is the understanding of the level-effect in marketing, where the effect of product attributes on utility is positively related to the number of levels present among choice alternatives. Knowing when consumers are sensitive to the competing levels of attributes is an important aspect of merchandising, selling and promotion. In this paper, we propose a model and a method for studying the level-effect in conjoint analysis. The model

combines perceptual theories in psychology to arrive at a non-linear specification of hyper-parameters in a hierarchical model. The method applies an experimental design criterion for efficient estimation of hyper-parameters. The proposed model and method are validated using a national sample of respondents.

****** May need to move this to "Contributions within discipline" (or at least move para 1). Move last two paras to "Contributions to other disciplines". Re-enter to deal with ends of lines.**

Findings:
The work has developed techniques which have advanced knowledge within the three disciplines of psychology, statistics and marketing. The work can be broadly summarized under the headings of modeling, prediction and experimental design. Much of the modeling work has combined psychological and marketing theories within a statistical framework.

A number of the projects have involved extensions and new ideas related to the Poisson race model and its use in modeling consumer decisions. For example, in one project, the model has been extended to include response times and the work has shown response times to be informative about respondents' preferences, diligence, and cognitive capacity allocated to the choice task. In another project, the model has been extended so that utility dominance and dominance on all aspects of an option can be distinguished. This work related to the Poisson race model has involved researchers from all three departments. The newly developed models predict decision behavior better than existing models. This has implications for psychological theories of decision making, modeling of consumer behavior in the market place and the development of the statistical theory underlying the models.

A number of other projects have involved modeling of consumer behavior through various forms of hierarchical Bayesian models. These models allow incorporation of consumer heterogeneity and the researchers have shown that they work well in the modeling of (i) the 'level effect' (known to be a phenomenon in both marketing and psychology, but had not been successfully modeled before), (ii) calibration of an individual's use of a conjoint scale, (iii) understanding the influence of variables that have an intermediate effect on choice, (iv) effect of advertising on consumer memory, and (v) calibration of individuals' use of a survey scale. The researchers have shown that the experimental designs that are used traditionally in marketing and other studies are not optimal for estimating the parameters in Hierarchical Bayesian linear models, and construction of optimal designs for this purpose has been developed.

Other projects crossing the disciplinary boundaries include (i) new methodology for modeling item response which allows different function shapes for different items and possibly nonmonotonic item response functions, thereby resulting in improved estimates of abilities, (ii) the use of epidemic-type point process models to sharpen the

understanding of how the marketing mix variables price, display, feature and product affect consumers' actions.

The main thrust of the work is applicable to any discipline that includes the study of how people make decisions and choices; for example, consumer science, industrial engineering, education, etc. Much of the statistical modeling and associated experimental design is applicable to any field which involves a population of non-homogeneous individuals or experimental material.

The work makes contributions to the general body of knowledge on the way in which people make decisions. This relates to all aspects of life, in general. In addition, the work related to marketing has implications in how advertisements are targeted to an audience, and the work in experimental design is also applicable in medical research and industrial product improvement.

Training and Development:
The research group has held a series of interdisciplinary seminars each quarter. These have been attended by 10-15 students and Visiting Scholars from the Statistics, Marketing and Psychology departments on a regular basis. The seminar series has been open to all students from the three departments. A few students have become sufficiently interested in the interdisciplinary work that they have requested to work with the research team. Other students have attended simply out of interest. In addition, the seminar series regularly attracts other faculty from the three departments, many of whom have given talks on related research. The talks given in the seminar series are posted on the website

http://www.stat.ohio-state.edu/~amd/seminar.html

In autumn 2004, Allenby and MacEachern ran a 'competition' for the best modelling of survey data collected by the American Marketing Association In winter 2004, MacEachern and Peruggia gave a series of talks on background knowledge needed for successful statistical work in the area. In subsequent quarters, the research students have all given talks on their current research or related work in the area. Other highlights include: spring 2005, Allenby posed a number of unsolved problems in Marketing and challenged the students to devise creative ideas for their solution; spring 2006, David Bakken from Harris Interactive talked on three problem areas of interest to market research; summer 2006, Allenby led a discussion group to try to address some of these problems. During the 2007-2008 academic year, the investigators on the grant gave talks on their current research and related papers. Visitors to the research group, Joseph Johnson (Psychology Department, Maiami University) and Bradley Jones (SAS, Inc.), gave talks related to their work in modeling consumer decision making and behavior.

Plans are progressing for a Graduate Interdisciplinary Specialization in Quantitative Studies in Consumer Behavior and a draft plan is being evaluated by interested departments.

A course 'Seminar on Marketing Models' was developed by Greg Allenby and has, so far been offered twice. The course focuses on recent developments and applications of Bayesian statistical methods in marketing. It is targeted to students interested in developing a conceptual understanding of quantitative models, and their operational translation into methods for data analysis. The past 10 years have seen a dramatic increase in the use of Bayesian methods in marketing. The purpose of this seminar is to review this literature and develop the tools needed for students to add to it. The first half of the course is devoted to developing a basic understanding of Bayesian methods and associated computational tools. The second half of the course will focus various aspects of analysis important to marketing and other applied disciplines.

A number of students from Pyschology, Marketing and Statistics have participated in the research program and the interdisciplinary seminars. These include graduated and current students:

GRADUATED:

Du, Juan (advisor: S.N. MacEachern) Judgement post-stratification for designed experiments. Ph.D. in Statistics, June 2006

Katsaounis, Tena (advisor: A. M. Dean) Equivalence of symmetric factorial designs and characterization and ranking of two-level split-lot designs Ph.D. in Statistics, November 2006.

Kao, Ling-Jing (advisor: G.M. Allenby) Data Augmentation for Latent Variables in Marketing Ph. D. in Marketing. August 2006

Liu, Qing (advisors: A.M. Dean, G.Allenby) Optimal experimental designs for hyperparameter estimation in hierarchical linear models Ph.D. in Statistics, August 2006

Merkle, Ed (advisor T. Van Zandt) Bayesian Estimation of Factor Analysis Models with Incomplete Data. Ph.D. in Psychology, December 2005.

Ruan, Shiling (advisors: S.N. MacEachern, A.M. Dean) Dependent Poisson Race Model And Modeling Dependence In Conjoint Choice Experiments Ph.D. in Statistics, March 2007.

Yu, Qingzhao (advisors: S.N. MacEachern, M. Peruggia) Bayesian model synthesis. Ph.D. in Statistics, August 2006

CURRENT

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