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The applicability of the punctuated equilibrium model to team development in science and engineering organizations

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THE APPLICABILITY OF THE PUNCTUATED EQUILIBRIUM MODEL TO TEAM DEVELOPMENT IN SCIENCE AND ENGINEERING ORGANIZATIONS

by

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A DISSERTATION

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We, the undersigned members of the Graduate Faculty of The University of Alabama in Huntsville, certify that we have advised and/or supervised the candidate on the work described in this dissertation. We further certify that we have reviewed the dissertation manuscript and approve it in partial fulfillment of the requirements of the degree of Doctor of Philosophy in Industrial and Systems Engineering.

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ABSTRACT

The School of Graduate Studies
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Title The Applicability of the Punctuated Equilibrium Model to Team Development in Science and Engineering Organizations

America is currently producing fewer scientists and engineers than its primary competitors, and this growing deficit of technical talent may affect its ability to maintain its leadership position on the world stage. Increasing productivity could enable science and engineering organizations to compete more effectively in the global marketplace. One way in which organizations may increase productivity is to make more effective use of their technical teams, and a better understanding of the team development process could help organizations build more effective teams. Team development models assist researchers and managers in terms of understanding and implementing the team development process.

This study evaluated the possibility that the Punctuated Equilibrium Model could complement or supplant existing models with regard to modeling team development in the science and engineering environment. The Punctuated Equilibrium Model is based on temporal phases in lieu of functional stages and it postulates that there is a transition that occurs at the calendar midpoint of a project. During the transition, the team reconsiders its strategy and reorganizes as necessary to successfully accomplish its objectives.

This is the largest study of the Punctuated Equilibrium Model to date. Three hundred ninety-four total teams were evaluated. This includes three hundred fifty-three short-term teams in a training environment and forty-one long-term teams in their real world environments. This is the second study of the Punctuated Equilibrium Model that focuses specifically on the science and engineering environment. Relative to other studies of the Punctuated Equilibrium Model,

this study attempts to improve on the balancing of Type I and Type II error by adopting a more effective methodology for evaluating the data than previous work. Finally, this is only the second study to utilize a survey instrument methodology, which facilitates the overall size of the study (i.e., number of teams evaluated).

Results indicated the Punctuated Equilibrium Model appears to lack applicability with respect to team development in the science and engineering environment. Only a small percentage of short and long term science and engineering teams appear to experience transitions and, with respect to long term teams, only a small percentage of those transitions appear to occur at the calendar midpoint. Of the teams that experienced a transition, neither short nor long term teams performed differently than teams that did not experience a transition. Furthermore, neither short nor long term teams that experienced transitions at their calendar midpoints performed better or worse than other (short or long term) teams that did not experience a midpoint transition.

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CHAPTER I

INTRODUCTION AND OBJECTIVES

A. Background

In the past century, technological innovation has enabled America to achieve and maintain its status as a global economic and military leader. However, the rise and evolution of the global economy over the past few decades has changed the landscape upon which all nations must compete and America's position as a global leader is being seriously challenged (Gates 2007, National Academy of Sciences et al. 2010, Will 2010). America is the only nation to set foot on the moon and it still leads in essentially all areas of technological innovation (e.g. energy, transportation, aerospace, communication, etc.). However, if America loses this leadership role, its economic and military leadership roles may be diminished as well (Friedman 2006, Gates 2007).

1. Staffing

In order to maintain its status as a global leader, America must retain its ability to be innovative technologically and this capability requires a strong technologically literate workforce. Meanwhile, America's science and engineering organizations are facing challenges related to staffing. Although increasing in absolute numbers, the size of the American science and engineering workforce appears to be increasing at a slower rate than the science and engineering workforces of its primary competitors (Friedman 2006). Multiple factors are driving the difference.

a. Science and Engineering Students

In recent years, a smaller percentage of American students have been choosing the science and engineering fields. Meanwhile, students in Russia, India, and China have been entering these fields in ever increasing numbers (Gates 2007). In the field of engineering alone, Asian universities now produce eight times as many bachelor's degrees as American colleges and universities (Friedman 2006).

In order to retain its leadership position, or at least to remain competitive on the global stage, America needs to continuously replenish its workforce with new and creative talent. Unfortunately, unlike the 1950's and 1960's, when America felt threatened by the launch of the Soviet Union's Sputnik, science and engineering are not attracting eager young talent sufficient in numbers to keep pace with the competition. The Space Race of the 1960's attracted a significant amount of talent to the science and engineering fields, but that talent has either retired or is close to retiring. There is no current equivalent to the Space Race of the 1960's that motivates younger people to choose science and engineering (*Philadelphia Inquirer* 2007, Gates 2007).

b. Aging Workforce

Age is another factor affecting the relative growth of the American science and engineering workforce. Most individuals in the science and engineering workforce are over 40 (National Science Board 2004) and, as of 2008, one in four aerospace workers are eligible to retire (Aviation Week and Space Technology 2007). In particular, the Federal Government is facing a wave of retirements (Goldfarb and Lee 2006, Barr 2009).

For example, the United States Army Corps of Engineers, in its Human Capital Strategic Plan (2009), recognized it is not recruiting and hiring at a rate sufficient to

replenish its ranks when considering the size of its retirement eligible population. The Plan also noted that the American Recovery and Reinvestment Act will require the Corps of Engineers to grow its workforce, hiring approximately 2,000 engineers beyond what it would normally need just to address turnover.

c. Foreign-born Talent

Another factor affecting America's ability to staff science and engineering organizations is the reduction in foreign-born talent choosing to migrate to America. In the past, foreign students came to America, acquired an education, and tended to remain in this country to work for an American company. Today, foreign-born students have more options and many are choosing to return home after receiving a degree. Furthermore, foreign-born students may even choose to pursue their education in their own countries as the opportunity for acquiring a high quality science or engineering education has increased significantly in foreign countries (Friedman 2006).

The availability of foreign-born talent has been further constrained by the events of September 11, 2001, which have negatively impacted the ability of many foreigners to gain access to the educational and employment opportunities that exist in the United States. These additional challenges have further complicated an already difficult situation and American competitiveness has suffered as a result (Friedman 2006).

2. Productivity

Katzenbach and Smith (1993) observed that teams are the most productive element at management's disposal. Teams, they claimed, outperform individuals when the task requires a variety of skills and experiences. However, Katzenbach and Smith (1993) also noted there is still much to learn about the team development process and

how to create more productive teams. They make the point that teams rarely achieve high performance status, which they describe as the most productive of teams.

One way to counter the disadvantage of a relative decrease in workforce numbers and to remain competitive in a global economy is through increased productivity enabled by a better understanding of the team development process. Wekselberg et al. (1997) and Wheelen et al. (1998) identified a relationship between team development and productivity. Wekselberg et al. (1997) studied firefighters and found that agreement on team goals correlated with increased performance. Wheelen et al. (1998) studied underwriting employees, hotel employees, and Japanese employees and found that a common perception of team dynamics correlated with performance.

3. Teams and Team Development (in Science and Engineering)

Katzenbach and Smith (1993, 92) defined a team as "a small number of people with complementary skills who are equally committed to a common purpose, goals, and working approach for which they hold themselves mutually accountable." They were not referring to science and engineering teams, specifically, but to teams in general. However, Benfield (2005) noted that science and engineering organizations are typically organized in teams. Utley (1995, 1) addressed the unique nature of science and engineering organizations, observing that they consist of …

> …trained professionals and technology oriented workers. Knowledge workers are hired for the competence brought to the job through formal education, logical thought processes, and experience. The knowledge worker is more than a pair of hands or a trainable entity that will perform the tasks assigned. The total capabilities of the individual are involved in achieving organizational objectives.

Given the unique nature of science and engineering organizations described by Utley (1995), it may be that team development models suited to non-technical organizations are not as applicable when it comes to modeling team development in science and engineering teams. Consequently, there is a need for further research focused specifically on team development models for the science and engineering environment. Although not within the focus of this study, it is possible that lessons learned from this research could be applicable to other types of knowledge worker-based teams (e.g., medical, legal, etc.).

B. Team Development Models

Team development models fall into two general categories, hierarchical and multi-sequence. Hierarchical models follow an exact sequence of functional stages whereas multi-sequence models do not follow a particular sequence of stages.

For the purpose of this study, the terms "team" and "group" were used interchangeably. This is consistent with how the terms have been treated in the literature as the interest in teamwork grew out of the group development domain.

In fact, Benfield (2005) and Knight (2006) treated these terms as synonymous when they evaluated the Tuckman (1965) group development model in terms of its applicability to science and engineering teams. In the realm of team development models, Benfield (2005) identified the Tuckman group development model, a hierarchical model, as the most popular team development model.

The Tuckman (1965) model is an assessment or compilation of fifty studies, which identifies four functional stages of team development. They are Forming, Storming, Norming, and Performing.

Both Benfield (2005) and Knight (2006) challenged the applicability of the Tuckman group development model to science and engineering organizations. Benfield (2005) could not separate "Norming" from "Performing" in long term teams and proposed a three-stage model instead (Forming, Storming, Norming/Performing). Knight (2006) did not observe "Storming" in short term teams and speculated that this may simply be a sign that science and engineering teams perceive storming as a part of norming, or a normal part of the way they communicate and carry out their activities. Prior to Benfield (2005) and Knight (2006), no empirical analysis had been conducted with respect to the Tuckman model, particularly with respect to science and engineering teams.

Given that the Tuckman model, the most popular hierarchical team development model, has been challenged and considering the unique nature of science and engineering teams, it makes sense to consider a multi-sequence team development model. As previously stated, multi-sequence team development models do not predict that teams will follow a specific order, or sequence, of development. It may be that a multi-sequence model is more likely to predict the behavior of science and engineering teams. The Punctuated Equilibrium Model (Gersick 1984) is one of the most recent multi-sequence team development models to be introduced and it has yet to be tested with respect to large numbers of science and engineering teams.

C. The Punctuated Equilibrium Model (Summarized)

The Punctuated Equilibrium Model, proposed by Gersick (1984), postulates that successful teams tend to experience strategic transitions at their temporal midpoints. Gersick initially conducted an observational study that involved eight real-world teams of varying backgrounds. In this study, seven of eight teams experienced successful transitions at their temporal midpoints and were successful in terms of completing their assigned tasks. The eighth team (Riverside) did not experience a successful transition and was not successful (Gersick 1984, 1988). The teams included in the study were as follows:

a. Novices: comprised of five first-year graduate-level management students

b. Strategic Planners: comprised of two first-year graduate-level management students and a second-year student

c. Policymakers: comprised of four first-year graduate-level management students

d. Centralized Fundraising Committee: comprised of professionals from four different organizations

e. Bank Group: comprised of four bank executives, all members of a larger management sub-committee

f. University Group: comprised of four faculty members and two administrators

g. Hospital Group: comprised of five hospital administrators

h. Riverside (Psychiatric Professionals): comprised of eighteen mental health professionals and three staff assistants

Gersick (1989) replicated this study in a laboratory, or training, environment with graduate-level management students a few years later. All teams were assigned the same task, which was to assume the role of professional advertising writers at a major urban

radio station. They had to develop a pilot commercial for a prospective client and they had one hour to complete the task. No written product was required, but they knew they would be filmed acting out the ad at the end of the hour. Each team was aware it had competition and an incentive was provided for the best ad, as judged by the client.

Again, seven teams experienced successful transitions at their temporal midpoints and were successful while one team did not experience a successful transition and was deemed unsuccessful in terms of task completion. Gersick concluded the transition was a critical element of the teams' development process and, therefore, a factor in its ultimate success.

D. Research Significance

Although the Punctuated Equilibrium Model has been studied with respect to its applicability to various types of teams, it is important to emphasize that none of the teams evaluated by Gersick were science or engineering teams. In fact, to date, there have only been seven additional studies of the Punctuated Equilibrium Model, not including Gersick's (1989) laboratory study, and only one of those studies, Durham (2008), focused on science and engineering teams. Consequently, this study is only the second study of the Punctuated Equilibrium Model to focus on science and engineering teams. Durham (2008) will be discussed in Chapter II.

This is also only the second study of the Punctuated Equilibrium Model to use a survey instrument approach. Miller's (1997) study was the first survey-based study and it is noteworthy that this dissertation analyzed data collected via the Group Process Questionnaire, the survey instrument developed by Miller (1997) for her study. It is also

worthy of note that Gersick was a participant in the validation of the Group Process Questionnaire.

Until now, the largest study of the Punctuated Equilibrium Model was Miller's (1997) evaluation of 42 teams (21 unique teams in two separate scenarios each). By comparison, this dissertation includes data from 394 teams. Consequently, this is the largest study of the Punctuated Equilibrium Model to date.

E. Contribution

Ultimately, whether the Punctuated Equilibrium Model proves to be applicable to science and engineering teams or not, the results of this research should enhance a manager's ability to foster effective teams. If applicable, engineering managers will know to look for and foster the transition at the temporal midpoint. If the model is determined to lack applicability, engineering managers will know they do not need to be concerned if their teams do not experience transitions, or if their transitions do not occur at the temporal midpoint as Gersick (1984) observed. Either way, the results of this study should contribute to a better understanding of team development in the science and engineering environment and further research should be enabled.

CHAPTER II

LITERATURE REVIEW

A literature review was completed to confirm the significance of the contribution of this research. After a brief discussion of the significance of team development and its relationship to science and engineering teams, an overview of team development models has been provided. Additionally, a detailed discussion of the Punctuated Equilibrium Model has been included along with a brief discussion of all eight previous studies of the Punctuated Equilibrium Model. Ultimately, it was determined that although the Punctuated Equilibrium Model has been tested in various environments, it has only once been tested with respect to teams in science and engineering organizations and more testing in this environment is merited.

A. Significance of Team Development

In 1992, a survey indicated that 82% of domestic organizations utilize teams. Almost half of these teams were considered permanent while slightly less than one-third were considered temporary. Almost one-fifth of these teams were considered cross-functional teams. The same survey also revealed that team members harbor very positive attitudes toward teams. Ninety percent of respondents felt that the quality of their products or services had been improved by utilizing teams. Eighty-five percent of respondents felt the quality of customer service had been improved for the same reason.

Generally, there was agreement among the respondents that teams were responsible for increasing productivity, morale, and profits (Gordon, 1992).

> The current emphasis on team effectiveness reflects the growing awareness that the complexity of work at this point in history requires collaboration. More work is conducted by groups of employees not for frivolous reasons but because it is the only way to accomplish tasks. Too much knowledge and too many different skills are required for any individual to successfully accomplish such complex tasks alone. The effectiveness and productivity of work groups, then, is of critical importance to organizational success. (Wheelen et al. 1998, 372)

Hackman (2002) noted that, compared to individuals, teams have more resources as well as a greater diversity of resources. Teams also have greater flexibility when it comes to deploying or using their resources.

Benfield (2005) observed that most science and engineering organizations are organized in teams while Burns (1995, 46) noted that “effective work teams can be a valuable asset to a firm.” As noted in Chapter 1, Katzenbach and Smith (1993) observed the team to be the most productive element at management’s disposal, but also observed that there is still much to learn about team development. Hackman (2002, viii), also expressed this sentiment when he noted, “team magic, as wondrous as it can be, is rarely seen.”

Wekselberg et al. (1997) and Wheelen et al. (1998) recognized a relationship between team development and productivity. Consequently, it is of value for engineering managers, team leaders, and even team members to recognize this relationship and contribute in such a way as to optimize their teams’ performance.

It should be noted that the words “team” and “group” are used interchangeably within this study. The American Heritage Dictionary (1976, 579) defines a group as “an

assemblage of persons or objects gathered or located together." Furthermore, it defines a team as "a group organized to work together: a team of engineers" (American Heritage Dictionary 1976, 1247).

B. Overview of Team Development Models

Team development models can be divided into two primary categories, hierarchical and multi-sequence. As shown in Figure 2.1, hierarchical team development models are sometimes referred to as "stage-based" or "sequential" models while multi-sequence models may be referred to as "non-sequential" models.

Hierarchical models are very rigid, requiring a team go through a set series of functional stages. Multi-sequence models are much more flexible, having no requirements related to the sequence in which teams must experience functional stages. There is no requirement to begin with a particular stage and there is no requirement with regard to order of progression.

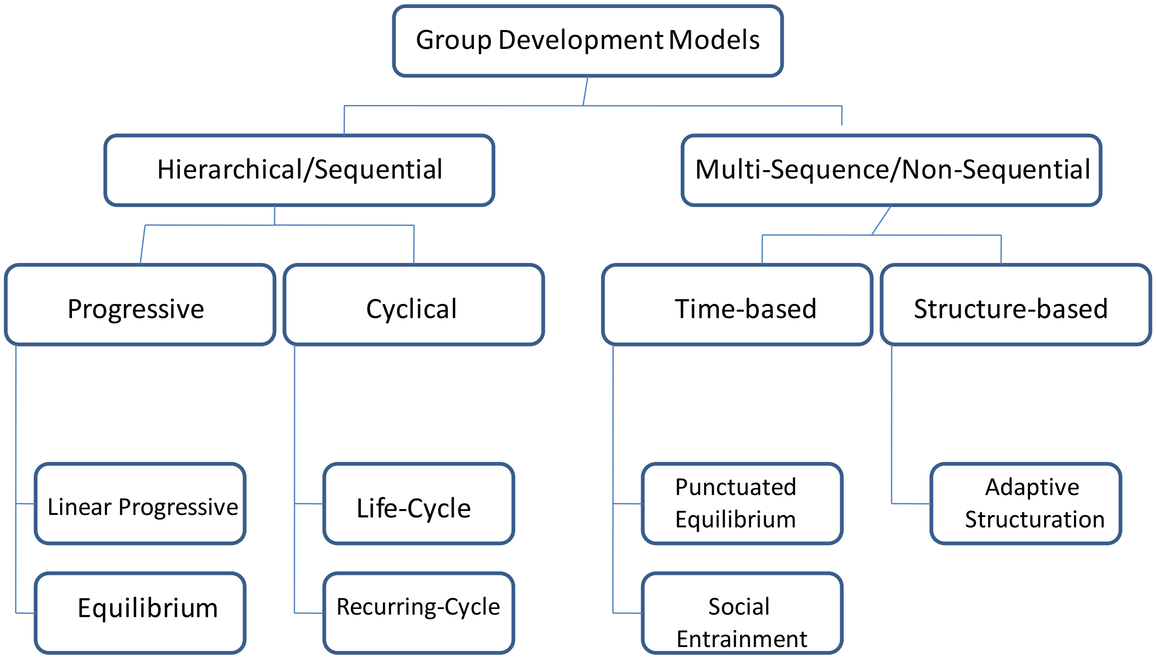


Figure 2.1 Team Development Models (Chidambaram and Bostrom 1996)

1. Hierarchical Models

Hierarchical models may be divided into progressive and cyclical models. Progressive models "imply an increasing level of group maturity over time" and can be further divided into linear progressive models and equilibrium models (Chidambaram and Bostrom 1996, 162).

Linear progressive models (Table 2.1) "suggest that groups move from an initial phase that represents a collection of independent individuals to one characterized by conflict, then by cohesion, and finally by productive work" (Chidambaram and Bostrom 1996, 162). These models mimic the development of individual persons from childhood to maturity.

Table 2.1 Linear Progressive Models (Benfield 2005)

Reference (Year)	Main Stages
Bennis and Shepard (1956)	Dependence, Submission, Counterdependence, Resolution, Independence, Enchantment, Disenchantment, Consensual Validation
Jacobson (1956)	Identification, Opportunity, Differentiation, Communication, Leadership/Influence, Endurance
Kaplan and Roman (1963)	Dependency Theme, Power Theme, Intimacy Theme
Schroeder and Harvey (1963)	Undifferentiated Mass, Conflict, Initial Integration, Intensive Integration
Tuckman (1965)	Forming, Storming, Norming, Performing

As discussed in Chapter 1, Benfield (2005) described the Tuckman (1965) team development model as the most popular team development model in the literature. The Tuckman model is a linear progressive model. The four primary functional stages of the Tuckman model are Forming, Storming, Norming, and Performing. A fifth, but lesser known stage, Adjourning, was later proposed by Tuckman and Jensen (1977).

Forming is the first stage of the Tuckman (1965) model and it is in this stage that team members become oriented to the task. They also come to understand their individual roles within the context of everyone else's roles.

Storming is the second stage and it allows for individual members to respond emotionally to the demands placed on him or her, individually. In this stage, conflict among individual members has to be resolved.

Norming is the third stage. This is the stage where team members come to terms with the demands placed upon them. The team gels and communication prospers.

Performing is the fourth stage and is considered the full operational mode for the team. This stage was considered the final stage when the model was initially introduced by Tuckman (1965).

Adjourning, a fifth functional stage, was later introduced by Tuckman and Jensen (1977). This stage accounts for termination of the team.

Benfield (2005) and Knight (2006) have challenged the Tuckman model's applicability to science and engineering organizations. Benfield was not able to separate "norming" from "performing" in his study of long term teams and proposed a three-stage model instead (Forming, Storming, and Norming/Performing). Knight did not observe "storming" in short term teams, but noted that science and engineering teams may simply observe storming as a normal part of their development process. It should be noted that neither Benfield (2005) nor Knight (2006) included Adjourning in their empirical studies of the Tuckman model.

Given that the Tuckman model has been challenged with respect to its applicability to science and engineering teams, it may be useful to consider a multi-sequence model. It may be that a multi-sequence model is more appropriate to model the unique nature of science and engineering teams.

The Equilibrium Model, posited by Bales et al. (Bales 1953, 1970; Bales and Strodbeck 1951; Heinicke and Bales 1953), "is based on the concept that the group is constantly trying to channel its effort between socioemotional and task-related needs" (Chidambaram and Bostrom 1996, 170). Efforts expended to satisfy one need can be done only at the expense of satisfying the other need.   Mature groups are those that have achieved equilibrium, or balance, between these competing needs. The three phases of

the Equilibrium Model are orientation, evaluation, and control. Bales and Heinecke (Bales 1953, Heinicke and Bales 1953) determined that the frequency of socioemotional acts increased between the orientation and control phases. In particular, they noted a significant increase in negative acts during the evaluation phase, which they attributed to the struggle for status.

Cyclical models "propose a nonlinear sequence of events" (Chidambaram and Bostrom 1996, 170). Cyclical are divided into two groups, life cycle models (Table 2.2) and recurring cycle models (Table 2.3).

Table 2.2 Life Cycle Models (Benfield 2005)

Reference (Year)	Main Stages
Dunphy (1964)	Dependency, Fight/Flight, Paring Work
Mills (1967)	Encounter, Testing, Negotiating, Production, Separation
Mann (1975)	Initial Complaining, Premature Enactment, Confrontation, Internalization, Separation
Spitz and Sadock (1973)	Initial Confusion, Interdependence, Disengagement
Braaten (1974)	Lack of Structure, Subgroup Emergence, Work Phase, Termination, Orientation
LaCoursiere (1974)	Orientation, Dissatisfaction, Production, Termination
Yalom (1975)	Orientation, Conflict, Cohesiveness, Termination

Lacoursiere (1980) described groups as living organisms that either mature or die, depending on how they react to stress. The life cycle model posits "that groups, like individuals, pass through the stages of birth, growth, and death" (Chidambaram and Bostrom 1996, 170). The final phase is considered critical as individual member behavior "changes in response to the impending end of the group" (Chidambaram and Bostrom 1996, 170). Unlike the linear progression model, which lacks regression, "the

life cycle model suggests that groups evolve over time, reach a peak, and then decline" (Chidambaram and Bostrom 1996, 170).

Table 2.3 Recurring Cycle Models (Benfield 2005)

Reference (Year)	Main Stages
Schutz (1958)	Integration, Inclusion, Control, Affection, Development
Bion (1961)	Dependency, Pairing, Fight/Flight
Hare (1973)	Latent Patern Maintenance, Adaptation, Integration, Goal Attainment
Slater (1966)	Inhibition, Revolt, Closeness, Pairing

The recurring-cycle model (Table 2.3) is based on the central "concept that, although groups progress over time" (Chidambaram and Bostrom 1996, 171), this is not always a permanent occurrence. Sometimes "they tend to return to the same position from which they started" (Chidambaram and Bostrom 1996, 171). The recurring-cycle model "combines progressive phases of group development with regressive phases to suggest that well-developed groups may frequently/regress to previous levels of development" (Chidambaram and Bostrom 1996, 171).

2. Multi-Sequence Models

Multi-sequence models are separated into two categories, time-based and structure-based. Time-based models, which "focus on the role of time in explaining group development (Chidambaram and Bostrom 1996, 172)," include the Punctuated Equilibrium Model and the Social Entrainment Model. The Punctuated Equilibrium Model will be discussed in detail in the next section.

The Social Entrainment Model (McGrath 1991, Kelly and McGrath 1988, McGrath and Kelly 1986) attempts to "explain how groups develop, manage conflict, and deal with ambiguity overtime using synchronization behaviors (Chidambaram and Bostrom 1996, 173)." Social entrainment is the synchronization of various processes over time among group members. "These coordination behaviors must occur at various levels: within individual team members, among team members, and within the social context in which they must operate" (Chidambaram and Bostrom 1996, 173). Internal or external stimuli may induce these behaviors. For example, "the issue of when (and for how long) group members listen to others primarily is an internally induced synchronization behavior, while the quickening pace of team activities due to a looming deadline is an externally induced behavior" (Chidambaram and Bostrom 1996, 173).

"Structure-based models of group development emphasize how groups adapt structures like facilitation, technology support, and other contextual variables to their needs over time" (Chidambaram and Bostrom 1996, 173). The most prominent structure-based model is the adaptive structuration model based on the adaptive structuration theory proposed by Giddens (1979) and evolved from the work of DeSanctis and Poole (1991). The model "suggests that groups differ significantly in the way they respond to externally imposed structures" (Chidambaram and Bostrom 1996, 173).

C. Punctuated Equilibrium Model (Detailed)

This dissertation is focused on the Punctuated Equilibrium Model because it is one of the more recent models to be proposed and one of the least researched models in the literature. Furthermore, as previously stated, this dissertation is only the second study

of the Punctuated Equilibrium Model with respect to science and engineering teams and it may be that a multi-sequence model is more appropriate than a hierarchical model in the science and engineering environment.

1. The Original Study

Gersick (1984, 1988) proposed the Punctuated Equilibrium Model, a multi-sequence team development model, after she studied eight short term teams, none of which were science or engineering teams. It should be noted that the first seven of the teams (listed and described in the following paragraphs) ranged in size from three to six members. The eighth team (Riverside) had eighteen members. The teams included in the study were as follows:

a. Novices: This team was comprised of five first-year graduate-level management students. Their task was to prepare a case on an affirmative action issue presented to the class by the personnel manager of a local business.

b. Strategic Planners: This team was comprised of two first-year graduate-level management students and a second-year student. Their task was to advise an inventor/entrepreneur with respect to growing his business.

c. Policymakers: This team was comprised of four first-year graduate-level management students. Each member was taking a special course on the public sector. Their task was to listen to lectures on international trade trends, formulate policy recommendations, write a report, and present the results to a panel of outside experts.

d. Centralized Fundraising Committee: This team was comprised of professionals from four different organizations. They came together at the request of one

of the four organizations, which wanted some assistance designing an evaluation process for its recipient agencies.

e. Bank Group: This team was comprised of four bank executives, all members of a larger management sub-committee. They were tasked to develop a new product for their company. The need or desire for the new product was driven by the passage of legislation, which allowed for a new type of account.

f. University Group: This team was comprised of four faculty members and two administrators. Each faculty member was from a different department. Their task was to respond to a recent internal proposal that the University should establish an interdisciplinary institute for computing.

g. Hospital Group: This team was comprised of five hospital administrators. Their task was to plan a semi-annual retreat to help bring the Department Heads of the Support Systems Division closer together. This retreat would be the fourth retreat in a series.

h. Riverside (Psychiatric Professionals): This team was comprised of eighteen mental health professionals and three staff assistants. They were tasked with planning for a major reorganization in an institution for emotionally disturbed adolescents.

Gersick (1984, 1988) chose the observational research method to execute her study, which actually began as an effort to support another study. After observing the first four teams (Novices, Strategic Planners, Policymakers, Centralized Fundraising Committee), she recognized a trend in behavior and so she extended the study to include four additional teams (Bank Group, University Group, Hospital Group, Riverside).

After observing all eight teams, she noted that all teams began with an initial framework of operations and continued with that framework until they reached the midpoint of their respective temporal (see Figure 2.2). At the temporal midpoint, seven of eight teams in her study, all except Riverdale, experienced what she labeled as a successful "transition," a paradigm shift which enabled the teams to reevaluate their strategies and create new operational frameworks.

The seven teams that experienced successful transitions came out of the transition much more productive and moved effectively toward a successful outcome. Gersick (1984, 1988) noted that the transition was a critical point in the evolution of the team, when it must change if it is to be viable in the next phase of its existence. It marked a distinct advancement in the team's progress. This advancement was based on the team's formation of a new and specific agreement about the overall direction the work should take.

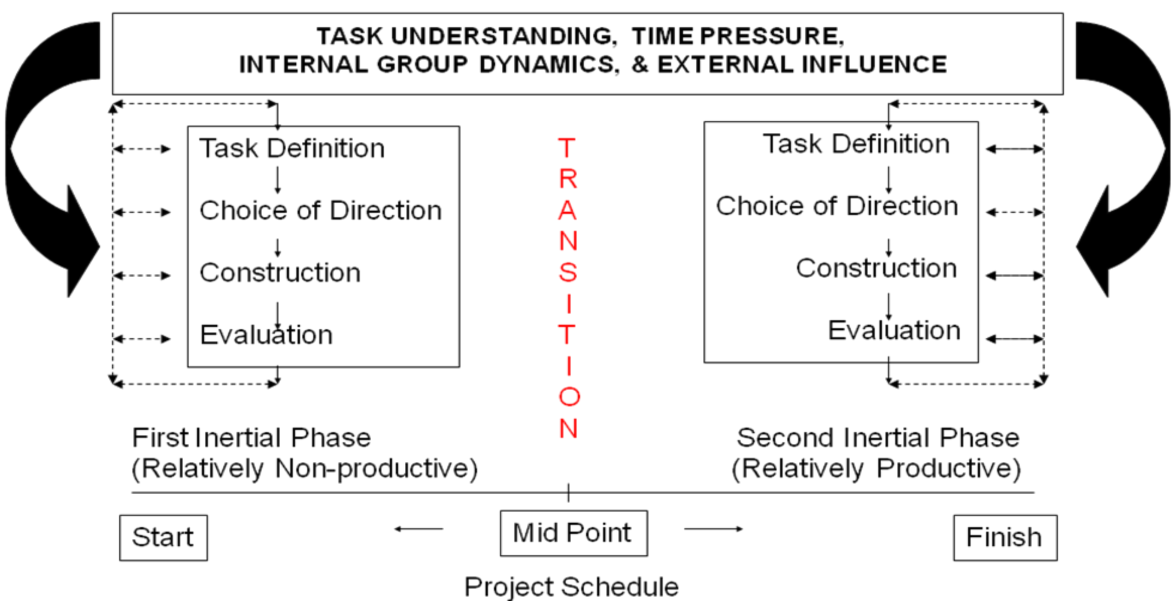


Figure 2.2 The Punctuated Equilibrium Model

2. The Task Hierarchy

In addition to the transition, Gersick (1984, 1988) observed what she referred to as the Task Hierarchy, which consisted of four elements. They were Task Definition, Choice of Direction, Construction, and Evaluation. These are described in more detail below.

Task Definition: The team comes to some agreement regarding what it is being asked to do. This means reaching, at an absolute minimum, a rudimentary agreement regarding the content of their assignment.

Choice of Direction: Given a task, the team chooses how to proceed. This requires some level of agreement with respect to the direction the team will take. Gersick (1984, 1988) observed two different paths being taken. One team might initially choose a method, or work strategy that it expected would lead to a solution. Other teams might focus initially on a particular solution to be constructed—with its method or strategy following from that choice.

Construction: This is the activity by which the teams' intentions are materialized. For the teams in Gersick's study, this meant building up and elaborating a body of ideas that the members agreed to include in their products.

Evaluation: Once the product had been constructed, it could be evaluated. Every team in her sample followed up its construction work with a period of critical evaluation, measuring its drafts against the criteria that they perceived would be used by audiences or users external to the group.

These elements appear to correlate to the stages of a hierarchical model, but the teams in her study did not appear to address the elements in any order. Instead, they began with different elements, some with Task Definition, some with Choice of Direction, and some with Construction. Then, they moved backward and forward or re-addressed elements as necessary. In some cases, some elements were not addressed at all.

3. Team Development Factors

Gersick (1984, 1988) observed that the midpoint transition appeared to result from the interaction of four team development factors. They are as follows:

Task Understanding: True understanding of the task is not typically immediate, but rather accumulated as the team struggles through the pre-transition phase. The collective knowledge gained during this relatively unproductive phase is instrumental in enabling the team to effectively adjust during the transition and set in motion a much more productive operational framework.

Time Pressure: Team members' perceptions of time spent and time remaining act as a catalyst to trigger the transition. Frustration with the lack of progress relative to time spent combined with the desire to make progress immediately motivates the team to reevaluate its strategy and execute with increased intensity.

Internal Team Dynamics: Transitional changes may make it (temporarily) both more compelling and easier for members to change the way they have been working together in the service of making progress on the task. This is an opportunity for progress.

External Influences from Task Delegators: Gersick (1984, 1988) observed that team members and task delegators are both stimulated to make contact with each other at the temporal midpoint. Gersick also noted that the delegator of the task had a hand in every team's transition.

Gersick further observed that, as teams approached the temporal midpoint, team members began to express frustration that sufficient progress had not been accomplished. They collectively recognized that the original framework was insufficient for affecting a successful outcome. Consistently, the task delegator became involved at this point, but it was the team that pushed itself through a paradigm shift and found a new framework that would be more effective. Coming out of the transition, seven of the eight teams were relatively productive and went on to accomplish their tasks successfully. The eighth team, Riverside, did not experience a successful transition and failed to complete its assigned task.

Gersick (1984, 70-71) listed seven indicators of the transition. They are as follows:

1. The transition occurred halfway through teams' calendar time.
2. Teams' work slowed down considerably just before the transition.
3. The transitional meeting was set apart from others by changes in meeting time, place, and/or attendance.
4. Teams members talked about feeling short on time or anxious to move ahead.
5. Teams made a compact burst of progress on their project designs.
6. "Slow" teams expressed relief and good feelings about this progress.
7. The transitional meeting was influenced importantly by contact between the team and its supervisor.

Gersick (1984, 1988) recognized the transition as the critical element of the Punctuated Equilibrium Model. She noted the transition provided each team the

opportunity to capitalize on the learning it had acquired during the first half of its lifecycle. Alternatively, if a team failed to capitalize on this opportunity, its likelihood of success was diminished.

D. Contemporary Studies of the Punctuated Equilibrium Model

Including a replication of the study by Gersick (1989), there have been eight studies of the Punctuated Equilibrium Model documented in the literature. They are as follows:

1. Gersick (1989)

As mentioned previously, Gersick replicated her study in a laboratory environment observing eight teams of MBA students and she observed similar results. Six teams had three members while two teams had four members.

All teams were assigned the same task, which was to assume the role of professional advertising writers at a major urban radio station. They had to develop a pilot commercial for a prospective client and they had one hour to complete the task. No written product was required, but they knew they would be filmed acting out the ad at the end of the hour. Each team was aware it had competition and incentive was provided for the best ad, as judged by the client.

Again, seven of eight teams experienced a successful transition (six of seven at the temporal midpoint) and were successful while the eighth team did not experience a successful transition and did not complete its task. Gersick (1989) concluded that the results of this study in a laboratory environment validated the results of her earlier study of naturally occurring teams in a field environment.

Gersick (1989) noted that since the Punctuated Equilibrium Model, including transitional behavior, could be replicated in a laboratory environment, this could enable further research. If the timing of the transition could be manipulated, this might be beneficial knowledge to managers and researchers.

2. Lim and Murnigham (1994)

Lim and Murnigham (1994) attempted to apply the Punctuated Equilibrium Model to two-person negotiation teams using an observation-based study. Ultimately, they determined that the model was not quite suitable to two-person negotiations as individual persons on opposite sides of a negotiation table are not really a team even though they may be pursuing a win-win situation. They are two separate teams with somewhat conflicting goals.

3. Miller (1997)

Only once before has the Punctuated Equilibrium Model been studied using a survey-based methodology. Miller (1997) studied both the Tuckman (1965) group development model and the Punctuated Equilibrium Model via a survey-based method. In fact, Miller (1997) developed the Group Process Questionnaire, the survey instrument that was employed to collect the data evaluated for this study. Benfield (2005) and Knight (2006) used the Group Process Questionnaire to collect data pertaining to the Tuckman group development model and the Punctuated Equilibrium Model. However, they only evaluated the data pertaining to the Tuckman group development model. Since the Group Process Questionnaire was a validated method of data collection for the Punctuated Equilibrium Model and since the data was available, the Group Process Questionnaire became the survey instrument used for this study.

Miller (1997) studied forty-two teams (i.e., twenty-one teams were each evaluated twice; two separate tasks were assigned to each team). With respect to the Punctuated Equilibrium Model, Miller found that 21 of 42 teams experienced a transition. Of the 21 teams that experienced a transition, 15 teams experienced that transition at the temporal midpoint. She declared the results to be a moderate endorsement of the Punctuated Equilibrium Model.

4. Seers and Woodruff (1997)

Seers and Woodruff (1997) were very critical of the Punctuated Equilibrium Model, claiming that it did not study team development at all, but merely studied “task pacing,” or “task progress.” They conducted two studies of their own, neither of which was focused on science and engineering teams and both employed an observational methodology.

The first study observed 50 undergraduate students from two upper-level management classes. These students were given both group and individual tasks related to writing term papers of various topics. They met in their groups five days per week over a thirty-day period. Additionally, each individual was asked to submit daily work logs. Seers and Woodruff (1997) focused primarily on the rate of progress prior to the temporal midpoint and the rate of progress after the temporal midpoint, but were interested to see if there would be a transition at the temporal midpoint.

The results of this study indicated the rate of individual and group progress was successfully modeled by raising the proportion of days elapsed to the fourth power, without a “marked discontinuity” at the temporal midpoint, which would have indicated a

transition might have occurred. They also noted that most of the time invested, as well as results produced, came in the last one-third of the temporal timeline.

The second study involved six teams of undergraduate students, but from only one of the upper-level management classes included in the first study. Each team was assigned two separate tasks.

The first task was to identify a short video that illustrated the exercise of interpersonal influence, present it to the class, and discuss how the concepts of power and influence applied. The second task was to present an analysis of a nationally known leader's prominent successes and failures in relation to the major topics covered in the course. In both cases, the majority of the work took place in the final third of the temporal timeline.

Seer and Woodruff (1997, 11) did acknowledge that "some evidence of a midpoint effect is seen in both studies, but the nature of the effect does not suggest a discontinuity between two stable phases, one before and one after the task midpoint." They concluded that the Punctuated Equilibrium Model confounds task pacing with group development. Task pacing, they claim, is a "task-deadline driven process, and group development appears to involve social factors which can extend beyond task-required interactions" (Seers and Woodruff, 11).

5. Okhuysen and Waller (2002)

Okhuysen and Waller (2002) evaluated the data collected in support of two previous studies (Okhysen 2001, Okhuysen and Eisenhardt 2001) to determine if the Punctuated Equilibrium Model was supported. Both data sets were composed of forty teams of four students in Introduction to Organizational Behavior courses. The

previous studies were focused "on the effects of familiarity and formal interventions on knowledge sharing and information exchange" (Okhuysen and Waller 2002, 9), and "did not examine whether the Punctuated Equilibrium Model proposed by Gersick (1988, 1989) was supported" (Okhuysen and Waller 2002, 8).

In their reexamination of the data, Okhuysen and Waller (2002, 12) "specifically focused on the Punctuated Equilibrium Model as it relates to task pacing in groups, that is, on how groups use time punctuation and temporal milestones to guide their work." They found that formal instructions and group composition could influence whether a team experiences task pacing or a midpoint transition.

They found task pacing occurred more frequently than the midpoint transition and concluded the midpoint transition is a subtle effect, resulting from conditions that are not well understood. They also noted that no development model, the Punctuated Equilibrium Model included, should be universally applied.

6. Chang et al. (2003)

Chang et al. (2003) evaluated the Punctuated Equilibrium Model by studying 25 Psychology student teams in a laboratory environment. The study showed that 16 of the teams experienced a transition, which was determined to be significant evidence of the Punctuated Equilibrium Model; however, only nine of the sixteen teams that experienced a transition did so at the temporal midpoint. Overall, Chang et al. considered these results to be a moderate endorsement of the Punctuated Equilibrium Model.

Chang et al. (2003) went on to compare and contrast stage-based models with the multi-sequence models (e.g. Punctuated Equilibrium Model) and determined they were not opposing models, but harmonious in their explanation of team development. Multi-

sequence models, such as the Punctuated Equilibrium Model, are more focused on how a team performs with regard to a specific task. Stage-based models, like the Tuckman Model, are more concerned with the overall development of the team, to include more components of the team's emotional and social interaction patterns.

Dennis et al. (2003) studied six newly-formed medical groups that worked on similar projects over a seven week period. Three of the groups worked "normally," while three used a Group Support System (GSS) that was new to them. The GSS consisted of a set of uncommon scripts that created conflict and prevented the groups from going right to work. The behavior of the three normal groups followed the Punctuated Equilibrium Model while the group behavior for the groups that used the GSS more closely resembled the stage model. Dennis et al. (2003) concluded that when group members do not share common scripts that fit together, they must first work to integrate their scripts and negotiate how they will work together before work on the task can begin (similar to the stage model).

Jayne (2004) noted that both Tuckman (1965) and Gersick (1984, 1988) discussed early periods of relative reduced measurable performance. For the Punctuated Equilibrium Model, it was the first half of the temporal timeline, and for the Tuckman Model, it was the Norming Stage. Jayne (2004) proposed that if a team were to manage these early phases from a knowledge creation perspective, then the team would be more likely to be successful.

7. Durham (2008)

Durham (2008) executed the first study of the Punctuated Equilibrium Model relative to science and engineering teams. He studied undergraduate science and engineering student teams competing in a design competition.

Like Gersick (1984, 1988), Durham (2008) used an observation-styled study and looked for indicators of the transition. Specifically, he observed each team for the following:

a. Conclude or abandon initial activities
b. Express urgency about finishing on time
c. Occurs at the temporal midpoint
d. New or renewed contact with external resources
e. New agreement on final path of work

Durham (2008) noted that most teams exhibited behavior consistent with those indicators; however, he also noted concern that “the team’s time was largely managed externally, with preset goals, milestones, and requirements.” Two of the five indicators (c and d) for which Durham (2008) was looking were actually built into the teams’ schedules by task delegators. Consequently, in this controlled environment, the teams may not have had the flexibility to fully experience urgency, or a transition, at the temporal midpoint.

E. Summary

Most organizations have adopted teaming to some extent and science and engineering organizations are no exception. Team development models allow for the visualization and application of specific team development theory. Models also enable research and evaluation of the effectiveness of the team development theory in question.

Team development models fall into two general categories, hierarchical and multi-sequence models. Arguably, the most popular team development model is the Tuckman group development model and this model has been challenged in two recent studies. The Punctuated Equilibrium Model, given its multi-sequence nature, may be more applicable to teams of knowledge workers like scientists and engineers that require flexibility to optimize their creative talents. Although the Punctuated Equilibrium Model has been tested in various environments, it has yet to be tested with respect to teams in science and engineering organizations.

The results of the research study outlined in this dissertation may help engineering managers and team leaders to produce more productive teams and increase America's ability to compete in a global business environment. At the very least, the results should help researchers in the pursuit of the ideal team development model for science and engineering organizations.

CHAPTER III

RESEARCH STATEMENT

A. Background

As described in the previous chapter, the Punctuated Equilibrium Model is a multi-sequence model introduced in 1984 that has not been evaluated to the extent that older models have been evaluated. Furthermore, the Punctuated Equilibrium Model has not been specifically evaluated with respect to team development in Science and Engineering organizations.

The "transition" is the critical element of the Punctuated Equilibrium Model. Gersick (1984) determined that successful teams tend to experience a transition at the temporal midpoint of their timelines, whereas unsuccessful teams tend to not experience a transition at the temporal midpoint.

B. Research Questions/Hypotheses Statements

This study is intended to evaluate the applicability of the Punctuated Equilibrium Model to team development in Science and Engineering Organizations. Gersick (1984) determined that successful teams experienced a transition, which she defined as an event that enables the team to reconsider its strategy and reorganize as necessary to

successfully accomplish its objectives. Furthermore, Gersick (1984) determined that successful teams tend to experience the transition at the temporal midpoint.

In order to evaluate applicability, each team was evaluated for the occurrence of a transition as well as the timing of that transition, if it occurred. Then the performance of the team was also considered. For the Punctuated Equilibrium Model to be determined applicable, successful teams must tend to experience transitions at the temporal midpoint. In other words, teams that experienced transitions should collectively outperform those teams that did not experience transitions, and those teams that experience transitions at the temporal midpoint should collectively outperform all other teams. If this study shows the Punctuated Equilibrium Model may have applicability to science and engineering teams, it may provide more information on the creation of more productive science and engineering teams.

There are four primary questions being addressed in this study. The first two questions pertain to the existence and timing of a potential transition. The last two questions pertain to team performance. They are as follows:

1. Do science and engineering teams experience transitions as a normal part of their development?
2. If so, do the transitions occur at the temporal midpoints of their project timelines?
3. Collectively, do teams that experience transitions perform better than teams that do not experience transitions?
4. Collectively, do teams that experience a transition at the temporal midpoint perform better than other teams?

In the form of hypotheses statements, the questions read as follows:

$H1_0$: Teams within science and engineering organizations do not experience a transition with respect to their development, thereby discounting the applicability of the Punctuated Equilibrium Model to science and engineering organizations.

$H1_1$: Teams within science and engineering organizations experience a transition with respect to their development, thereby endorsing the applicability of the Punctuated Equilibrium Model to science and engineering organizations.

$H2_0$: Teams that experience transitions do not experience them at the temporal midpoint, thereby discounting the applicability of the Punctuated Equilibrium Model to science and engineering organizations.

$H2_1$: Teams that experience transitions do so at the temporal midpoint, thereby endorsing the applicability of the Punctuated Equilibrium Model to science and engineering organizations.

$H3_0$: The existence of a transition has no affect on the performance of a science and engineering team, thereby discounting the applicability of the Punctuated Equilibrium Model to science and engineering organizations.

$H3_1$: The existence of a transition affects the performance of a science and engineering team, thereby endorsing the applicability of the Punctuated Equilibrium Model to science and engineering organizations.

$H4_0$: The existence of a transition <u>at the temporal midpoint</u> has no affect on the performance of a science and engineering team, thereby discounting the applicability of the Punctuated Equilibrium Model to science and engineering organizations.

H4$_1$: The existence of a transition at the temporal midpoint affects the performance of a science and engineering team, thereby endorsing the applicability of the Punctuated Equilibrium Model to science and engineering organizations.

C. Contribution to the Field

This study is unique in many ways. First, only one prior study of the Punctuated Equilibrium Model has focused specifically on science and engineering teams. Given the unique nature of science and engineering teams, another study focused on team development in this realm is merited. Second, this is only the second study of the Punctuated Equilibrium Model using a survey-based methodology. Third, this is the largest study of the Punctuated Equilibrium Model, including a total of 394 teams spread across the public and private sectors.

As engineering managers and team leaders look for ways to ensure the effective development of their teams, they may look to the results of this study to provide knowledge concerning the applicability of the Punctuated Equilibrium Model to team development in science and engineering teams. Leaders and managers as well as team members will know whether it is normal and/or purposeful to experience transitions and, furthermore, whether it is beneficial to experience those transitions at the temporal midpoint of their project timelines. Researchers may use the knowledge acquired through this study as they continue to pursue the ideal team development model.

CHAPTER IV

RESEARCH METHODOLOGY

A. Background

Two samples of science and engineering teams were evaluated in the execution of this study. Both samples were acquired as the byproduct of a data collection process executed independently by researchers for other studies. Benfield (2005) collected data pertaining to long term teams in a real-world environment and Knight (2006) collected data pertaining to short term teams in a training environment. The sample of long term teams was inclusive of both the private and public sectors while the sample of short term teams was exclusively public sector.

Both researchers, Benfield (2005) and Knight (2006), evaluated the Tuckman Model and each used the Group Process Questionnaire (GPQ) developed by Miller (1997), which solicits data with respect to both the Tuckman and Punctuated Equilibrium Models. The data each researcher collected with respect to the Punctuated Equilibrium Model was not evaluated prior to the execution of this study. Furthermore, it is note-worthy that both Benfield (2005) and Knight (2006) were critical of the Tuckman Model's applicability to the development of science and engineering teams, making the study of the Punctuated Equilibrium Model all the more valuable.

B. Research Sample

1. Long Term Teams

a. Makeup

Benfield (2005) solicited the data pertaining to long term teams directly from twenty-four science and engineering organizations, including private-sector companies as well as government entities. A breakdown is included in Table 4.1.

After gaining permission from each company or government entity, surveys were distributed electronically to each individual team member. Obviously, time could not be provided to each team member and so each team member had to decide for him or herself when to complete the survey, if at all. Consequently, the response rate and the quality of the data received were not quite as high as the data received with respect to short term teams in a training environment.

After filtering to ensure the quality of the data (see Section G for filtering process specifics), long term teams included in the study (41 out of 122) had a mean size of 8.1 members with a standard deviation of 4.7. Additionally, teams that had not completed their task were excluded from the study.

Table 4.1 Organization Data – Long Term Teams (Benfield 2005, 57)

Organization Type	Number of Organizations	Number of Teams
Army System Program Management Office	11	42
Army Program Executive Office	3	31
High Technology Industry	3	22
NASA Research Center	4	14
Army Research and Development Center	3	13
Total	24	122

b. Conclusion

Benfield (2005) compared the demographics of the long term team database (Table 4.2) to that of the science and engineering sector in general using data from the National Science Foundation's Scientists and Engineers Statistical Data System (SESTAT 2001). He confirmed that the collective demographic profile of the database was similar to, or representative of, the science and engineering sector in general.

Table 4.2 Demographics – Long Term Teams (Benfield 2005, 60)

Demographic	Categories	SESTAT (2001)	Research Sample
Gender	Male	65%	77%
	Female	35%	23%
Ethnicity	White	82%	91%
	Black	5%	4%
	Hispanic	4%	3%
	Asian or Pacific Islander	9%	2%
Professional Years	0-10	17%	20%
	10-20	26%	44%
	20-30	30%	28%
	30-40	20%	6%
	40+	7%	2%
Education	Bachelor's	73%	48%
	Master's	19%	46%
	Doctorate	8%	6%

2. Short Term Teams

a. Makeup

Knight's (2006) sample of short term teams, although collected in a training environment, consisted of team members that are normally members of technical teams

within the Department of Defense. Federal Government and active duty military employees dominated this database. A breakdown is provided in Table 4.3.

Although the team members were not working with their real-world teams, they were performing simulated tasks in a training environment. The average number of years of experience within the short term team database was 11.29 years.

After filtering to ensure the quality of the data (see Section G for filtering process specifics), short term teams that remained part of the study (353 out of 368) had a mean size of 5.3 members with a standard deviation of 0.9. Short term teams were evaluated in a laboratory, or "training," environment. They were given projects that took a matter of hours and were given the surveys immediately thereafter. Consequently, the response rate for short term teams was much higher than that for long term teams as they were essentially captive.

Table 4.3 Organization Data – Short Term Teams (Knight 2006, 29)

Organization Type	Distribution
Active Military	24.10%
Government Civilians	69.34%
Private Industry	2.11%
Other	4.46%

b. Conclusion

Although Knight (2006) collected data from technical teams in a training environment, these "students" were actually technical team members in their real-world environments and were organized in teams and assigned typical real-world projects to complete as part of the training class. Therefore, it was assumed by Knight that the

demographic profile of this database reflected the demographic profile of the science and engineering sector. The minimal duration of each team's activity was 30 minutes, but longer was considered to be better. Table 4.4 compares the demographics of the short term database to the science and engineering sector in general using data from the National Science Foundation's Scientists and Engineers Statistical Data System (SESTAT 2001).

Table 4.4 Demographics – Short Term Teams (Knight 2006, 28-29)

Demographic	Categories	SESTAT (2001)	Research Sample
Gender	Male	65%	68%
	Female	35%	30%
Education	Bachelor's	73%	49%
	Master's	19%	36%
	Doctorate	8%	2%

C. Research Method Chosen

Since the data evaluated for this study was collected by other researchers, it was not necessary to choose a data collection methodology. Benfield and Knight chose the survey-based method because of its relative high efficiency in terms of time and cost as compared to other methods (Brewerton and Millward 2001, Benfield 2005, and Knight 2006). The survey-based method also allows for a more objective evaluation than other methods such as the observation method, which was the method chosen by Gersick (1984, 1988) and Miller (1997), who have evaluated the Punctuated Equilibrium Model.

Although the methodology for collecting the data was determined by Benfield (2005) and Knight (2006), the methodology for analyzing the data was dictated by the objectives of this dissertation. Multiple methodologies were considered and evaluated

based on their ability to balance Type I and Type II error. The evaluation process will be discussed in Section H (Research Approach) of this chapter.

D. Survey Selection

Benfield (2005) and Knight (2006) used two surveys to collect data, the Group Process Questionnaire (GPQ) (Miller 1997) and the Halfhill (In Press) Business and Engineering Technology Survey. The GPQ gathers data on a team's behavioral characteristics while the Halfhill Survey collected data pertaining to performance. Both sets of data from each researcher were included in this study, allowing this study to evaluate the applicability of long-term and short-term science and engineering teams.

As discussed in Chapter 3, there are four hypotheses being tested in this study. The first two hypotheses are focused on determining whether science and engineering teams follow the Punctuated Equilibrium Model. The last two hypotheses are focused on determining if those teams that follow the Punctuated Equilibrium Model perform better than those teams that do not follow the Punctuated Equilibrium Model.

Miller (1997) validated the GPQ via expert evaluation and Dr. Gersick was one of the evaluators participating in the validation of the GPQ. Miller focused her study on the transition point. She notes that, according to Gersick, the transition point is the critical element of the Punctuated Equilibrium Model.

The GPQ contains five questions for each team member to indicate whether they observed transition-related behavior and, in conjunction with each question, the team member also notes the timing of the transition-related behavior, if transition-related behavior was observed. The five questions pertaining to the transition are as follows:

1. Work went through a period of major change
2. A new approach quickly crystallized
3. New agreements were made about the direction to take the work
4. There was a noticeable change in strategy
5. The group abandoned their old approach and made a fresh start.

If the response was positive, timing data was required for the data to be useful. A negative response did not require timing data. Timing data was measured on a 50-point scale, the middle third of which was considered the temporal midpoint, in accordance with the precedence established by Miller (1997). Defining the temporal midpoint as the middle third of the timeline was arguably a liberal definition that allowed for a favorable evaluation of each transition's timing and, ultimately, the Punctuated Equilibrium Model.

The Halfhill (In Press) Business and Engineering Technology Survey measures a team's performance based on team members' responses. Each team member answers five questions, qualitatively (strongly disagree, disagree, neutral, agree, strongly agree), and those answers are converted to quantitative scores (1, 2, 3, 4, and 5, respectively). The five questions are as follows:

1. This group understands how to accomplish its task.
2. This group is very good at planning how to accomplish their work objectives.
3. This group meets all objectives for work completed.
4. This group's work is always of the highest quality.
5. This group takes initiative in solving problems and decision making.

Ultimately, for each team, the quantitative scores for all questions and all respondents are averaged to determine the team's performance score.

E. The Group Process Questionnaire (GPQ)

1. Validity

Miller (1997) utilized twelve subject matter experts to validate the GPQ. She focused on content and construct validity. Only questions/statements upon which all subject matter experts agreed were included in the survey. Ultimately, the GPQ was left with 31 questions, 16 of which pertain to the Punctuated Equilibrium Model and 5 of which pertain specifically to the transition point.

2. Reliability

Reliability is a measure of consistency, or an inverse measurement of the potential for error (Brewerton and Millwad 2001). The reliability analysis included all 394 teams, 41 long term teams and 353 short term teams. An individual cronbach's alpha was calculated with respect to both long and short term teams and the GPQ's ability to identify the occurrence of a transition. They were 0.829 and 0.870, respectively. Scores between 0.600 and 0.700 are considered the minimum acceptable reliability of an instrument's construct (Kline 1986 and 1993a). Given this minimum threshold, the above scores indicate very high reliability for the GPQ in this application.

F. Halfhill Business and Technology Survey

1. Validity

In addition to Halfhill (In Press), Fortune (2005) assessed concurrent and content validity of the Halfhill Business and Technology Survey and determined the survey instrument was valid. Fortune (2005) evaluated the instrument with respect to student

and practicing engineering teams. The performance-related questions were determined to adequately measure team performance (Benfield 2005).

2. Reliability

Halfhill (In Press) reported the cronbach's alpha associated with the performance portion of the Business and Engineering Technology Survey to be 0.93. Fortune (2005) calculated Cronbach's alphas of 0.88 and 0.81 with respect to student and practicing engineers, respectively.

G. Filtering Criteria and Filtering Results

In order to ensure the quality of the data being included in the study, the data was filtered with the intent of removing unproductive responses. Filtering criteria were established at the individual and team levels.

In order to be included in the study, an individual respondent was required to have provided useful input to at least 80% (i.e., four of the five) transition-related questions in the Group Process Questionnaire. In order to be useful, "Yes" responses required timing data. If a respondent marked "Yes," but failed to include timing data, the response to that question was not considered useful.

In order to be included in the study, a team was required to have 50% of its team members pass the individual filter. The total number of team members included not only the respondents, but also those team members that may not have responded to the survey at all. This requirement proved especially challenging for the long term teams, as no one was physically present to encourage the team member to fill out the survey and time attributed to filling out the survey was time taken away from other activities.

For example, if a team consisted of five members, at least three members had to pass the individual filter. If two team members did not respond at all, the other three members had to pass the individual filter in order for the team to be included in the study.

Also, a team was required to have at least two individual team members respond to the surveys. For example, a team of two members would not be included in the study if only one team member responded to the survey.

Finally, a team had to be essentially finished with its task. Completion was determined using the completion data collected by the GPQ. The GPQ includes three questions pertaining to completion. They are as follows:

1. The final product was fine tuned
2. The work was completed
3. Members were confident about the work

In order to be designated as complete, the positive response rate relative to completion had to be 50% or above for the respondents from that team. Only respondents were included in this assessment (i.e., the positive response rate was not diluted by team members that did not respond to the survey at all).

1. Long Term Team Filtering Results

Data was collected with respect to 122 teams in a real world environment (Benfield 2005). After filtering, 41 teams were included in this study. With respect to the real world environment, the task of targeting employers and gaining permission to solicit input from their employees is much more challenging than collecting data in a

training environment. Consequently, on a relative basis, it was expected that more long term teams than short term teams would be filtered out of or excluded from the study.

2. Short Term Team Filtering Results

Data was collected from 368 teams in a training environment (Knight 2006). After filtering, data from 353 teams were included in this study. The high quality of the data was attributed to the fact that the team members were relatively captive for the purpose of training. The survey was distributed immediately after completion of each team's project and adequate time was provided to complete the survey.

H. Research Approach

Methodologies used to evaluate each of the four individual hypotheses (converted to a simple question) are described below:

1. Do science and engineering teams experience transitions as a normal part of their development? (H1)

    a. Overview

Three general methodologies were considered for analyzing the data with respect to the first hypothesis (H1). General strengths and weaknesses of each methodology were identified. However, it was decided that the methodology that best balanced Type I and Type II error would be the methodology selected.

Type I error is the conclusion that a transition did occur when, in fact, it did not occur (i.e., reject the null hypothesis when the null hypothesis is true). Type II error is the conclusion that a transition did not occur when, in fact, it did occur (i.e., fail to reject the null hypothesis when the null hypothesis is false). In order to determine which

methodology provides the best balance of Type I and Type II error, hypothesis testing and Bernoulli trials were utilized.

b. Methodologies Considered

i. Miller's Methodology (MM)

Miller's (1997) study was the only other study of the Punctuated Equilibrium Model to employ a survey instrument methodology (vs. an observation-based methodology). In order to determine whether a transition was experienced by a particular team, Miller (1997) decided that a team's positive response rate to transition-related questions needed to cross a certain threshold. Miller (1997) established the threshold by calculating the mean positive response rate (by team) and adding one standard deviation. For her sample, the mean positive response rate was 35% and the standard deviation was 25%, resulting in a threshold of 60%. Any team that crossed the threshold was deemed to have experienced a transition.

For the short term teams included in this study, the mean positive response rate was calculated to be 26.3% and the standard deviation was calculated to be 14.7%. Consequently, the mean positive response rate for short term teams was determined to be 41%.

For the long term teams included in this study, the mean positive response rate was calculated to be 39.1% and the standard deviation was calculated to be 15.2%. Consequently, the mean positive response rate for long term teams was determined to be 54.3%.

Miller (1997) did not consider Type I and Type II error in setting the threshold and actually used the term "arbitrary" to describe the threshold she had calculated.

Consequently, two additional methodologies were entertained for the purposes of this study. They were the Minimum Individual Positive Response (MIPR) and 50.1% methodologies.

ii. The Minimum Individual Positive Response (MIPR) Methodology

The MIPR methodology required that for a transition to be determined to have occurred each respondent must have responded positively to a minimum number of transition-related questions or behaviors. The advantage of this methodology was that a minority of team members could not drive the determination that a transition occurred without a minimal endorsement from other team members. The minimum numbers of one (MIPR-1), two (MIPR-2), and three (MIPR-3) positive responses per respondent were all considered.

The weakness of the MIPR-1 methodology is that a relatively low number of positive responses could dominate the results for a team. For example, assuming a minimum of one positive response per respondent, if each of five respondents responds positively to only one of five opportunities each, only five of twenty-five opportunities would be positive. Yet, a transition would have been determined to have occurred. The same example could apply in the case where only two positive responses are required per respondent (i.e., ten of twenty-five opportunities could drive the determination that a transition occurred).

iii. The 50.1% Methodology

In the 50.1% methodology, team respondents had to collectively respond positively to a majority of the transition-related questions in the questionnaire. For

example, if a team had five respondents and each member had five opportunities to declare that a transition did occur, the team respondents collectively had twenty-five opportunities to say that a transition occurred. For a transition to have been determined to have occurred, the respondents must have collectively answered positively to at least thirteen of the transition-related questions.

The weakness of this methodology is that a minority of respondents could dominate the results for any one team. For example, a transition would have been determined to have occurred if only two of the five respondents had responded positively to each of the five transition-related questions while only three more positive responses came from the fifteen opportunities presented to the other three respondents. In fact, one or two respondents could have responded negatively to all of the transition-related questions and it could still have been determined that a transition had occurred.

c. Hypothesis Testing and Type I/II Error

The process of inferring from a sample whether or not to accept a particular statement about a population is called hypothesis testing. The statement itself is referred to as the null hypothesis (H_0). The null hypothesis is tested based on the sample data. The null hypothesis is either *rejected*, meaning the evidence from the sample casts enough doubt on the hypothesis for us to say with some degree of confidence that the hypothesis is false, or it is *accepted*, meaning it is not rejected. Rejecting the null hypothesis means the evidence indicates the alternate hypothesis (H_1) is true (Conover 1980).

For the evaluation of each methodology under consideration for this study, the underlying hypotheses statements (not to be confused with the hypotheses statements laid out in Chapter 3), were H_0: $\pi \leq 0.5$ and H_1: $\pi > 0.5$, where π equals the probability that any individual team member will provide a positive response to a transition-related question.

Typically, in hypothesis testing, the researcher attempts to minimize both Type I and Type II error. In doing so, the level of significance (α) or maximum probability that a true null hypothesis will be rejected, is usually set at a low value of 0.01 or 0.05. Knowing the level of significance and the sample size enables the researcher to determine the maximum probability that a false null hypothesis will be accepted (β). Unfortunately, to decrease Type I error tends to increase Type II error (and vice versa) when dealing with a fixed sample size (Conover 1980).

As previously stated, it is desired to select a methodology for evaluating whether or not a team experienced a transition that best balances Type I and Type II error and controlling α, especially at such a low level, would not enable a robust evaluation of the three general methodologies. Consequently, in this case, it is not useful to control α.

The ideal methodology would determine that no transition occurred when $\pi \leq 0.5$, consistent with H_0. Alternatively, the methodology would determine that a transition occurred when $\pi > 0.5$, consistent with H_1. Figure 4.1, P(Accept Transition) vs. π, illustrates the ideal curve for the probability of accepting a transition. The methodology that most closely mimics the ideal curve is the methodology that will minimize Type I and Type II error. It is desired that the values of both α and β be close to 0.50 at the maximum value of π, under H_0, which is = 0.5. By balancing Type I and Type II error

(vs. setting α = 0.5), this allows for a favorable evaluation of the Punctuated Equilibrium Model.

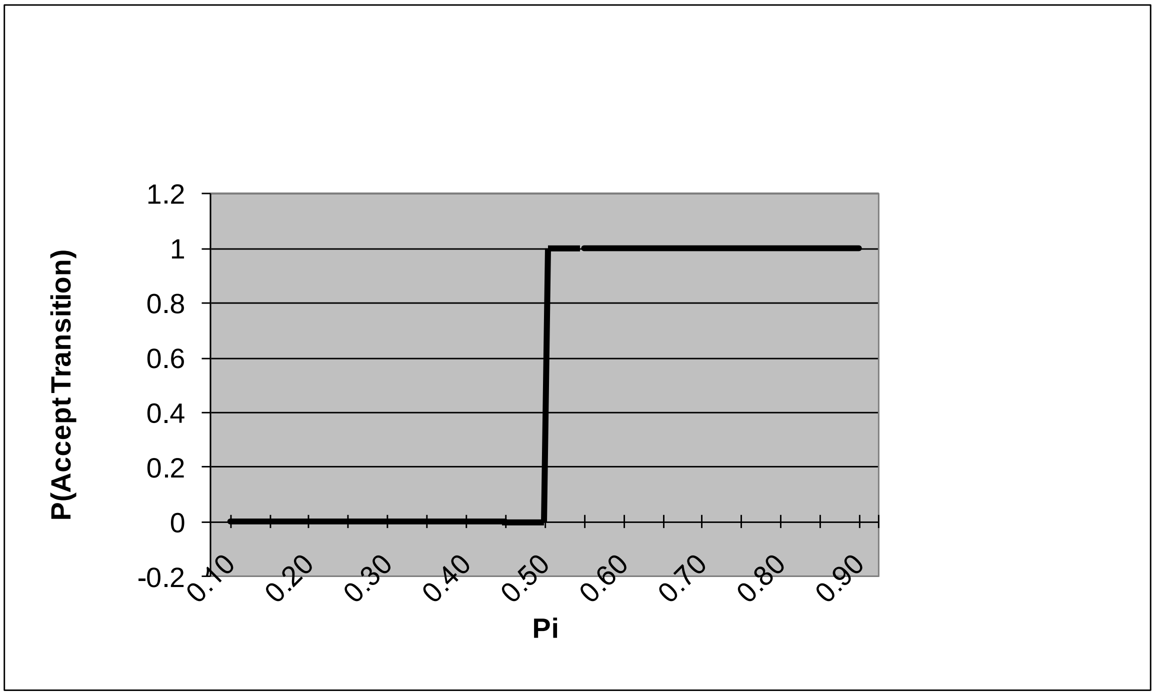


Figure 4.1 Ideal Curve for P(Accept Transition) vs. π

e. Bernoulli trials

In order to evaluate how well each methodology balances Type I and Type II error, Bernoulli trials were utilized. Bernoulli trials, sometimes referred to as binomial experiments, are based on the binomial distribution and have the following properties:

i. Independent Trials

There were five questions in the survey that pertained specifically to the transition. Consequently, the number of trials within the experiment equals 5n, where n equals the number of team members responding to the survey.

The trials must be independent; that is, the outcome of one trial does not affect the outcome of other trials. This means not only that individual team members' responses must be independent from one another, but that each response (to an individual question) from an individual team member must be independent of that individual team member's response to every other question. Having a valid and reliable survey instrument helps to assure that each response from an individual team member is independent of his or her other responses. Furthermore, no pattern was observed in the data indicating that individual team members felt compelled to answer all questions in the same manner, either positive or negative.

Different methods were used to collect the data for the two different databases. Nevertheless, with respect to independence among individual team members, it is assumed that all of the respondents responded to the survey individually.

1. Short Term Teams

In the case of the short term teams, surveys were completed in the classroom and oversight was provided, which helped ensure there was no collusion among team members. At the conclusion of the team's task, faculty distributed the surveys to the individual team members who completed the surveys individually and returned them to the faculty before leaving the classroom. No opportunity for collusion existed.

2. Long Term Teams

The surveys were distributed to long term team members via e-mail and the respondents provided their input electronically. It is assumed that each respondent was sitting at his or her personal computer when responding to the survey. In reviewing the

data, no evidence of collusion existed. Additionally, there was no incentive that would have motivated respondents to spend the time to align their responses.

ii. Two Possible Outcomes

Each trial can result in just two possible outcomes (i.e., success or failure). In this case, a positive response affirming the occurrence of transitional behavior would be considered a success while a negative response would be considered a failure.

iii. Constant Probability of Success

The probability of success, denoted by π, is the same for every trial. While individual perception based on individual experience may play a role in discounting this assumption somewhat, a constant probability of success is a valid assumption because the individual team members within each team are observing and experiencing the behavior of the same team. Furthermore, the five questions of the survey instrument are measuring a single construct, which makes the experiments very straightforward. The probability of a respondent responding in a positive manner is dependent primarily on the respondent observing transitional behavior, as described by the individual question in a valid, reliable survey instrument.

iv. Notation for Bernoulli trials

n: The number of team members responding to the survey.

$5n$: The number of Bernoulli trials. Each respondent answered five questions.

π: The probability of success of an individual trial (i.e. one team member responding to one question).

k: The number of positive responses from one individual in a Bernoulli trial

c: The maximum number of successes in a Bernoulli trial that do not reject the null hypothesis.

B(c; 5n, π): Binomial probability – the cumulative probability that a 5n-Bernoulli trial results in c or fewer successes, when the probability of success on an individual trial is π. This formula is useful for calculating the cumulative probability associated with Miller's Methodology as well as the 50.1% Methodology because it accommodates the responses of the entire team.

B(c; 5, π)^n : Binomial probability – the cumulative probability that a 5-Bernoulli trial results in c or fewer successes, when the probability of success on an individual trial is π, further accounting for the number of team members responding to the survey. This formula is useful for calculating the cumulative probability associated with the Minimum Individual Positive Response because it focuses on the individual positive response rate before converting to a team-level probability.

S: A random variable representing the sum of the positive responses across team members and questions.

v. Equations

Binomial equations were derived and plotted against the ideal curve on the range of $\pi = 0$ to 1. The binomial equations for each methodology were derived as follows.

1. Miller's Methodology

P(Accept Transition) = P(S > c) = 1 – B(c: 5n, π), where c equals the integer immediately less than (41%)5n for short term teams and c equals the integer immediately less than (54.3%)5n for long term teams. For n = 5, c = 10 for short term teams (0.41 x 5 x 5 = 10.3) and c = 13 for long term teams (0.543 x 5 x 5 = 13.6), in accordance with the thresholds calculated for the two types of teams.

2. Minimum Individual Positive Response

In this case, the equation must focus on the individual positive response rate (k). If k positive responses (k = 1, 2, or 3) is required from each individual, then c = k – 1 (c =

0, 1, 2), as c is the maximum number of successes in a Bernoulli trial that do not reject the null hypothesis.

In general, for MIPR-k: P(Accept Transition) = $(1 - B(c: 5, \pi))^n$, where c = k -1.

3. 50.1% Methodology

P(Accept Transition) = P(S > c) = 1 – B(c: 5n, π), where c where c equals the integer immediately less than (50.1%)5n. For n = 5, c = 12 (0.501 x 5 x 5 = 12.5). Unlike Miller's Methodology, the threshold is set at 50.1% without regard for the positive response rate of the underlying database.

f. Miller's Methodology and Type I/Type II Behavior

The x-axis (π) in Figure 4.2, Miller's Methodology for Short Term Teams with Five Respondents, represents the probability that any individual team member will provide a positive response to a transition-related question. The y-axis represents the probability that a transition will be accepted (i.e., determined to have occurred). The ideal curve (Figure 4.1) represents the desired results, where the probability that a transition will be accepted is zero when $\pi < 0.5$ and the probability that a transition will be accepted is 1.0 when $\pi \geq 0.5$. Any difference between the ideal curve and the decision rule's curve, or P(Accept Transition), represents Type I or Type II error. If the difference occurs when $\pi < 0.5$, the error is Type I error. If the difference occurs when $\pi > 0.5$, the error is Type II error.

In the case of Miller's Methodology for short term teams (MM-ST), the methodology appears to favor Type I error when n = 5. Observing the intersection of the

P(Accept Transition) curve with the ideal curve at $\pi = 0.5$, it can be determined that $\alpha = 0.79$ and $\beta \leq 0.21$.

For the practical purpose of evaluating the methodology with respect to the hypotheses, (H_0) a transition actually occurred when $\pi > 0.5$ (for any individual team) and (H_1) no transition occurred when $\pi \leq 0.5$ (for any individual team), the values $\pi = 0.3$ and $\pi = 0.7$ have been chosen. Arguably, these are values of π (far enough from $\pi = 0.5$) where a dependable methodology should provide predictable results.

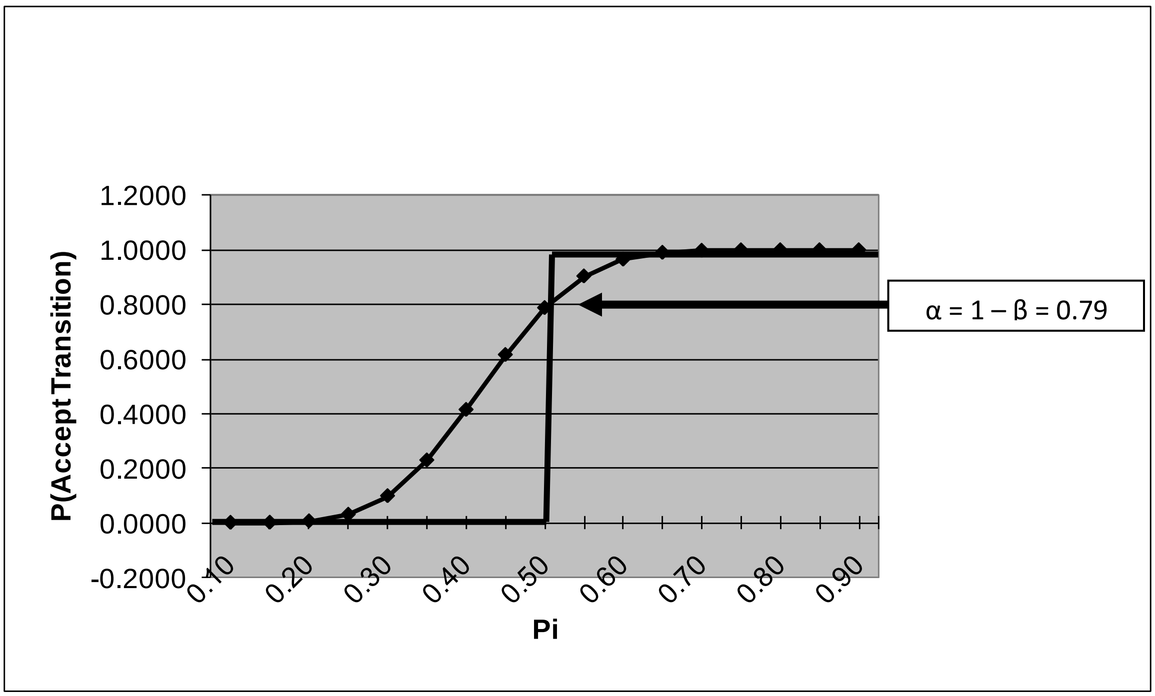


Figure 4.2 Miller's Methodology for Short Term Teams with Five Respondents

For $\pi = 0.3$, P(Accept Transition) = 0.1 for MM-ST. Consequently, the methodology would indicate that a transition had not occurred, consistent with the null

hypothesis. For π = 0.7, P(Accept Transition) = 1.0. Consequently, the methodology would indicate that a transition had occurred, consistent with the alternate hypothesis.

Referencing Figure 4.3, Miller's Methodology for Long Term Teams (MM-LT) with Five Respondents, it appears that MM-LT slightly favors Type II error when n = 5. Observing the intersection of the P(Accept Transition) curve with the ideal curve at π = 0.5, it can be determined that α = 0.35 and β ≤ 0.65.

For π = 0.3, P(Accept Transition) = 0.01. Consequently, the methodology would indicate that a transition had not occurred, consistent with the null hypothesis. For π = 0.7, P(Accept Transition) = 0.96. Consequently, the methodology would indicate that a transition had occurred, consistent with the alternate hypothesis.

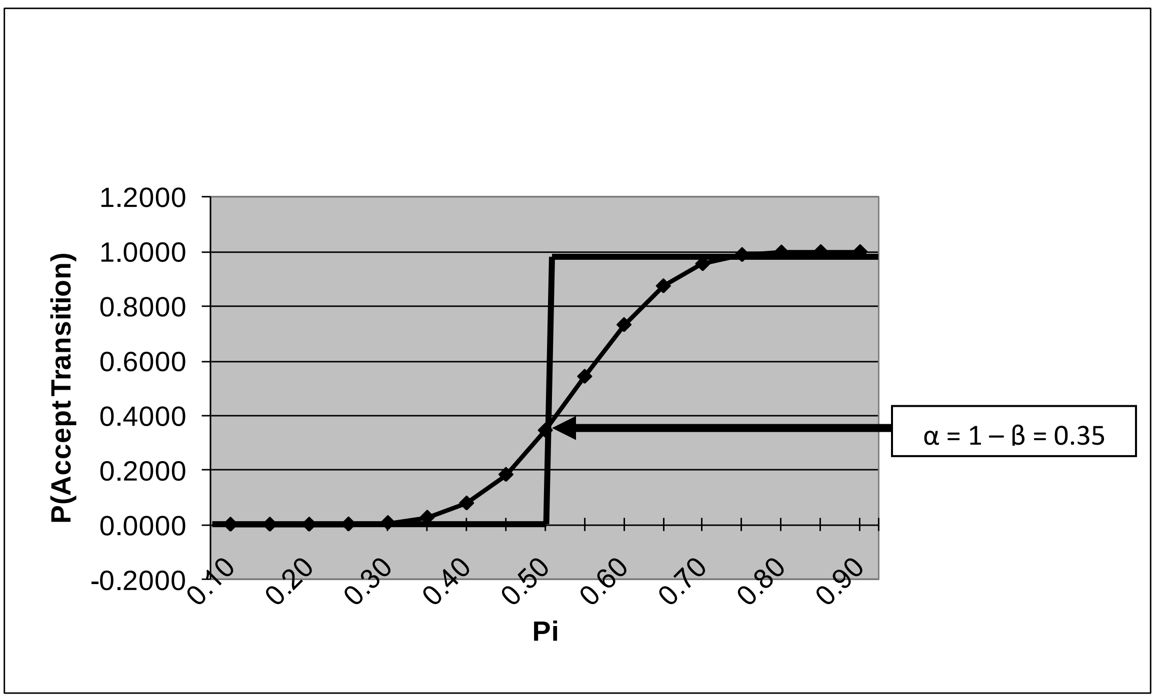


Figure 4.3 Miller's Methodology for Long Term Teams with Five Respondents

The difference in the effect of implementing Miller's Methodology to the two separate samples (short and long term teams) is driven by the difference in positive response rates for the two separate samples. The mean positive response rate for short term teams was 26.3% with a standard deviation of 14.7%, resulting in a threshold of 41%. The mean positive response rate for long term teams was 39.1% with a standard deviation of 15.2%, resulting in a threshold of 54.3%. Different threshold values result in different values of c in the decision rule. See section H.1.b.v.2. Minimum Individual Positive Response.

The lower threshold appears to favor Type I error, while the higher threshold appears to favor Type II error. Consequently, Miller's Methodology allows the balance of Type I and Type II error to vary along with the positive response rate.

g. MIPR Methodology and Type I/II Error

With respect to Type I and Type II error (reference Figure 4.4, Minimum Individual Positive Response-1 with Five Respondents), it was discovered that MIPR-1 favors Type I error more than Miller's Methodology for short term teams (MM-ST). Observing the intersection of the P(Accept Transition) curve with the ideal curve at $\pi = 0.5$, it can be determined that $\alpha = 0.85$ and $\beta \leq 0.15$.

For $\pi = 0.3$, P(Accept Transition) = 0.4. Consequently, the methodology would indicate that a transition had not occurred, consistent with the null hypothesis. For $\pi = 0.7$, P(Accept Transition) = 0.99. Consequently, the methodology would indicate that a transition had occurred, consistent with the alternate hypothesis.

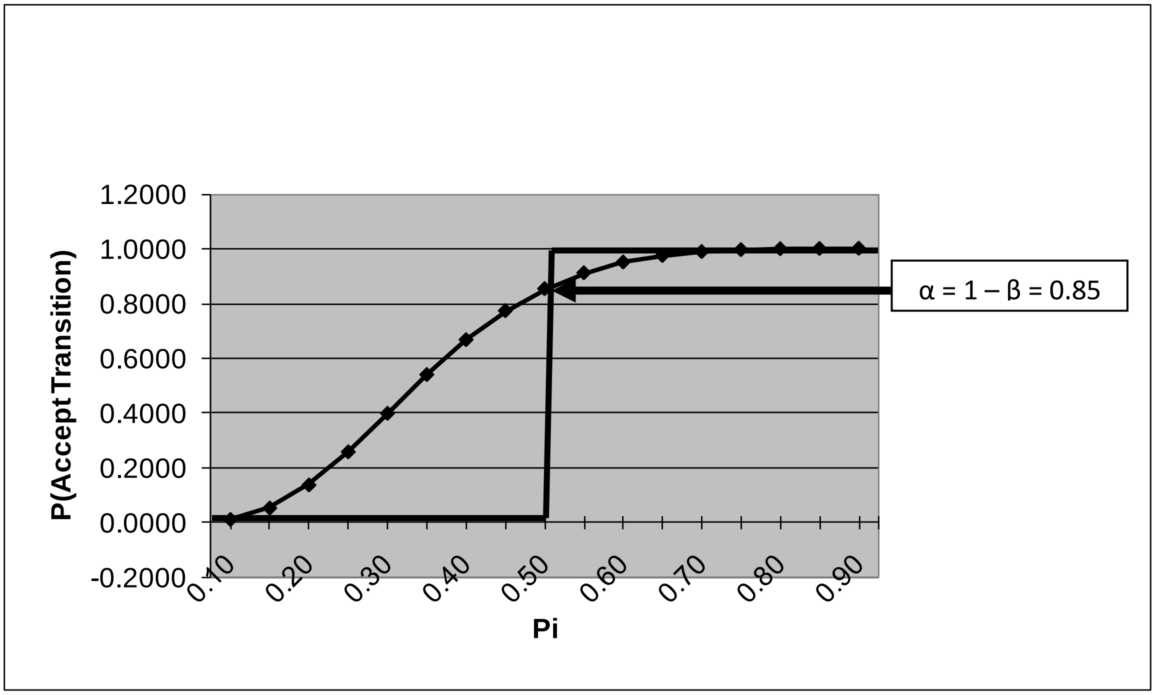


Figure 4.4 Minimum Individual Positive Response-1 with Five Respondents

Requiring two positive responses of each respondent (MIPR-2) reduced Type I error at the expense of increasing Type II error (for five respondents), and resulted in a better balance than MIPR-1 when n = 5 (reference Figure 4.5, Minimum Individual Response-2 with Five Respondents). Observing the intersection of the P(Accept Transition) curve with the ideal curve at $\pi = 0.5$, it can be determined that $\alpha = 0.35$ and $\beta \leq 0.65$.

For $\pi = 0.3$, P(Accept Transition) = 0.02. Consequently, the methodology would indicate that a transition had not occurred, consistent with the null hypothesis. For $\pi = 0.7$, P(Accept Transition) = 0.86. Consequently, the methodology would indicate that a transition had occurred, consistent with the alternate hypothesis.

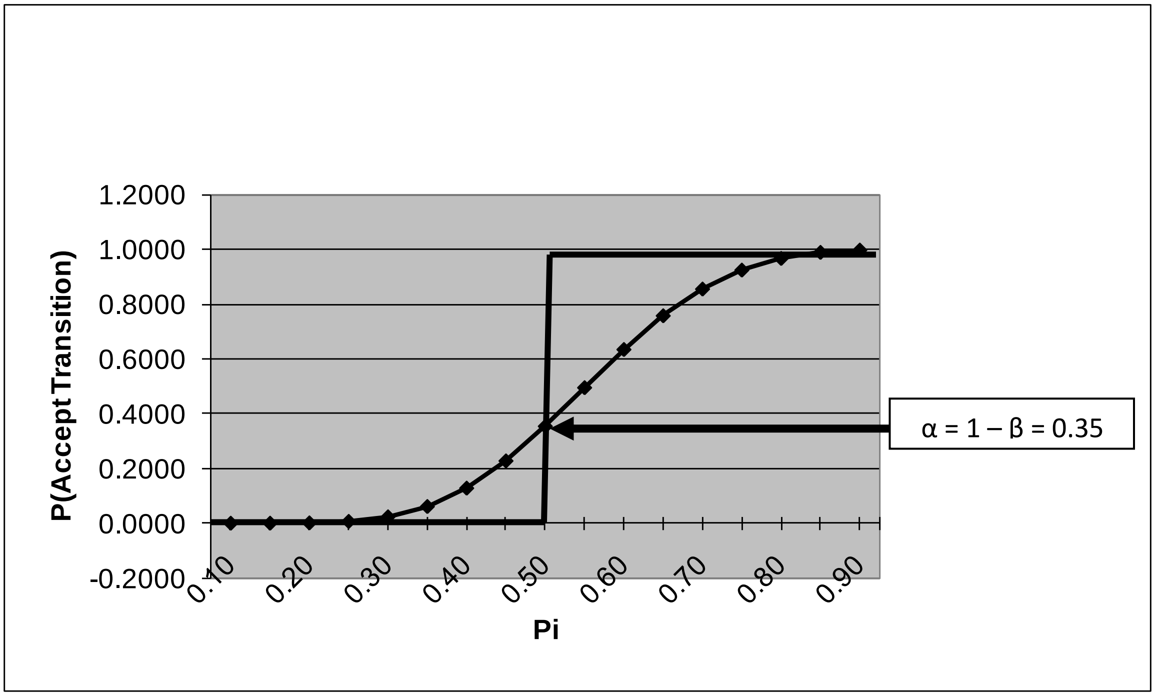


Figure 4.5 Minimum Individual Positive Response-2 with Five Respondents

It was found that requiring three positive responses from each respondent (MIPR-3) minimized Type I error at the sacrifice of maximizing Type II error (reference Figure 4.6, Minimum Individual Positive Response-3 with Five Respondents). This approach favored Type II error more than either Miller's Methodology for long term teams (MM-LT) or MIPR-2. Observing the intersection of the P(Accept Transition) curve with the ideal curve at $\pi = 0.5$, it can be determined that $\alpha = 0.03$ and $\beta \leq 0.97$.

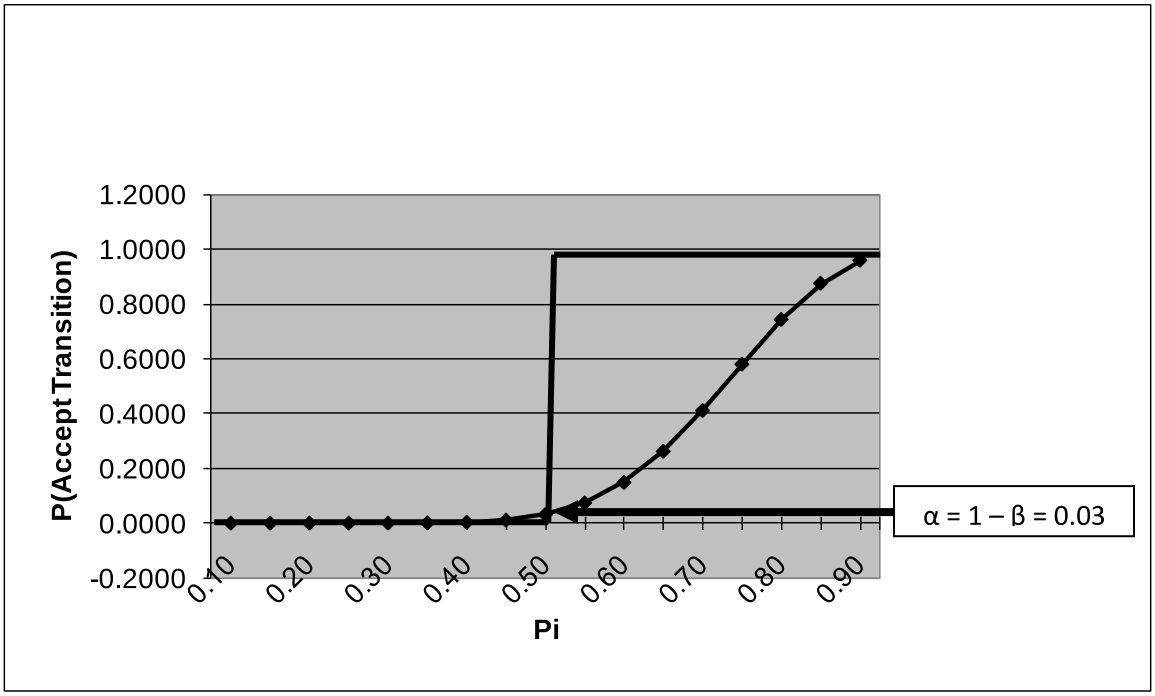


Figure 4.6 Minimum Individual Positive Response-3 with Five Respondents

For $\pi = 0.3$, P(Accept Transition) = 0.00. Consequently, the methodology would indicate that a transition had not occurred, consistent with the null hypothesis. For $\pi = 0.7$, P(Accept Transition) = 0.41. Consequently, the methodology would indicate that a transition had not occurred, which would be inconsistent with the alternate hypothesis. Of the two general methodologies considered so far, Miller's Methodology would be preferred because, given the thresholds calculated, it balances Type I and Type II error better than the Minimum Individual Positive Response methodology.

h. 50.1% Methodology and Type I/Type II Error

The 50.1% methodology (reference Figure 4.7, 50.1% Methodology for Teams with Five Respondents) favored neither Type I nor Type II error in the case of teams with five respondents. Observing the intersection of the P(Accept Transition) curve with the

ideal curve at π = 0.5, it can be determined that α = 0.5 and β ≤ 0.5. For teams with five respondents, the 50.1% methodology most closely mimics the ideal curve and is the preferred methodology of the three general methodologies considered.

For π = 0.3, P(Accept Transition) = 0.02. Consequently, the methodology would indicate that a transition had not occurred, consistent with the null hypothesis. For π = 0.7, P(Accept Transition) = 0.98. Consequently, the methodology would indicate that a transition had occurred, consistent with the alternate hypothesis.

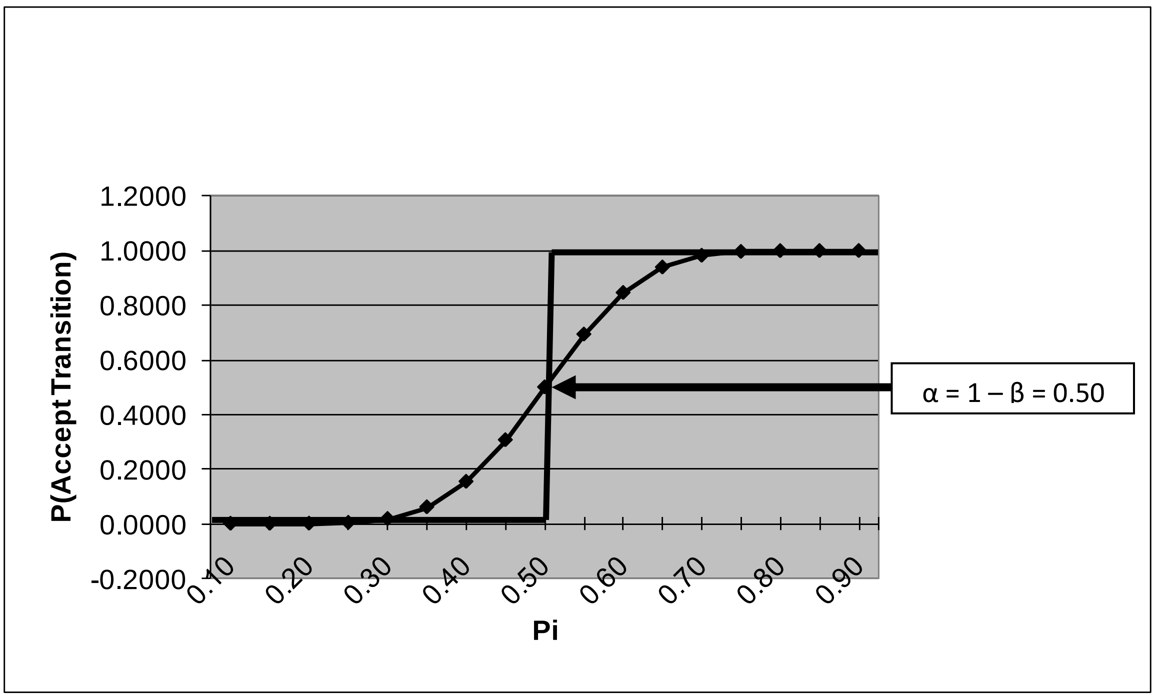
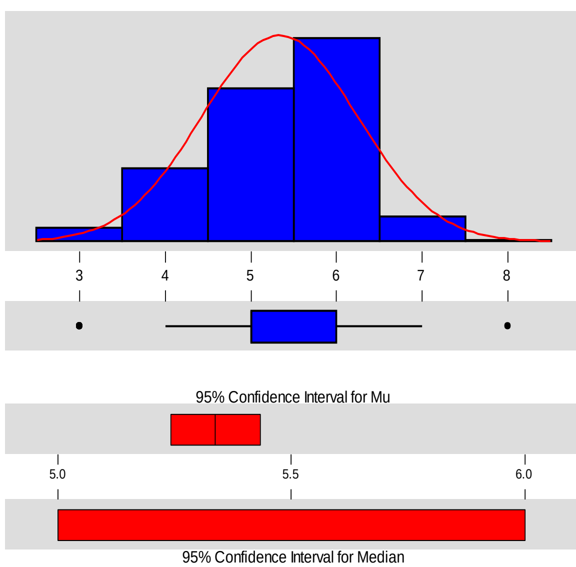


Figure 4.7 50.1% Methodology for Teams with Five Respondents

i. Sensitivity Analysis (Team Size)

The case where a team has five members is typical for either database, short or long term teams. However, each database varied in team size. Consequently, it was necessary to evaluate each of the methodologies with respect to a range of respondents.

Reference Figure 4.8, Short Term Team Descriptive Statistics. The mean number of respondents for short term teams was 5.3 with a standard deviation of 0.9. The minimum number of respondents for short term teams was 3 and the maximum team had 8 members.



Variable: ST

Anderson-Darling Normality Test

A-Squared:	21.157
P-Value:	0.000
Mean	5.33711
StDev	0.91217
Variance	0.832056
Skewness	-4.2E-01
Kurtosis	-1.3E-01
N	353
Minimum	3.00000
1st Quartile	5.00000
Median	5.00000
3rd Quartile	6.00000
Maximum	8.00000

95% Confidence Interval for Mu

5.24163 5.43260

95% Confidence Interval for Sigma

0.84948 0.98493

95% Confidence Interval for Median

5.00000 6.00000

Figure 4.8 Short Term Team Descriptive Statistics

Reference Figure 4.9, Long Term Team Descriptive Statistics. The mean number of respondents for long term teams was 8.1 with a standard deviation of 4.7. The

minimum number of respondents for long term teams was 3 and the maximum team had 25 members.

In addition to teams with five respondents, each methodology's ability to balance Type I and Type II error was evaluated with respect to teams with two, three, four, six, seven, eight, nine, ten, fifteen, and twenty-five respondents. The figures illustrating these results are included in Appendix C.

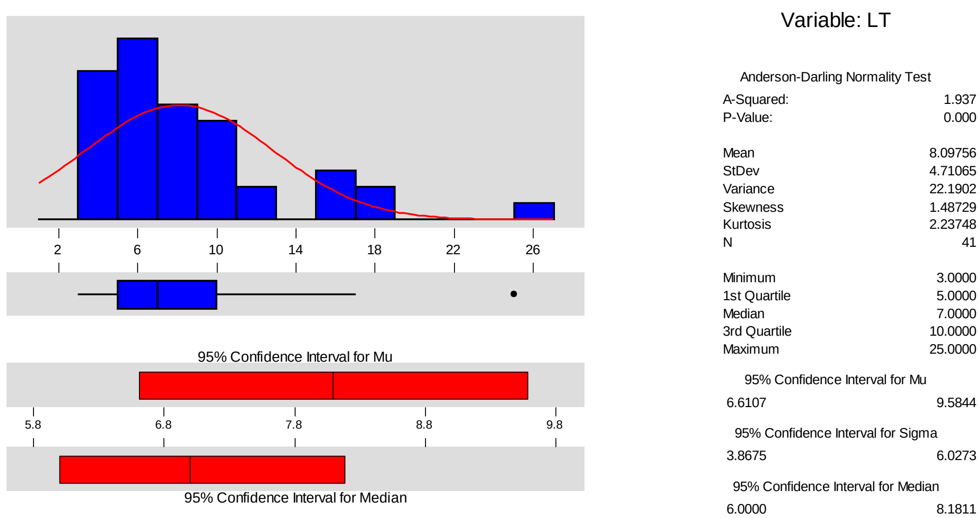


Figure 4.9 Long Term Team Descriptive Statistics

It should be noted that, among the methodologies evaluated, the 50.1% methodology best balanced Type I and Type II error in all cases except two. When a team had only two or four respondents, the 50.1% methodology was as effective as Miller's Methodology at balancing Type I and Type II error. In all other cases, the 50.1% methodology dominated.

For all cases of teams with an odd number of members, the 50.1% methodology best balanced Type I and Type II error of all the methodologies considered. For all cases with an even number of members, the 50.1% methodology slightly favored Type II error, but still balanced Type I and Type II error as well as or better than any of the other methodologies. As the size of the team increased, the 50.1% methodology more closely mimicked the ideal curve.

Tables 4.5 and 4.6, General Results Relative to Type I and Type II Error (Odd and Even Numbered Teams, respectively), summarizes the results by methodology. The results are consistent for all teams with five or more respondents, except in the case of a team that has 25 respondents. In this case, MIPR-1 slightly favors Type II error. However, there are a few exceptions with smaller teams. For example, MIPR-2 favors Type I error when evaluating teams with less than four respondents.

Table 4.5 Results Relative to Type I and Type II Error (Odd Numbered Teams)

	50.1%*	MIPR-1	MIPR-2	MIPR-3	MM-ST	MM-LT
Type I	-	+	-	-	+	-
Type II	+	-	+	+	-	+
	+ means biased towards; - means biased against					

Table 4.6 Results Relative to Type I and Type II Error (Even Numbered Teams)

	50.1%*	MIPR-1	MIPR-2	MIPR-3	MM-ST	MM-LT
Type I		+	-	-	+	-
Type II		-	+	+	-	+
	+ means biased towards; - means biased against					

Ultimately, the 50.1% Methodology was chosen because it balances Type I and Type II error as well as any methodology for teams with only two or four respondents and it balances Type I and Type II error better than any of the other methodologies for teams with three or more than four respondents (up to and including twenty-five respondents). It is worthy of note that the smallest teams evaluated had only two respondents while the largest team had twenty-five respondents.

Utilizing the 50.1% Methodology to determine whether a team incurred a transition, the number (and percentage) of teams determined to have experienced transitions was identified. Additionally, hypothesis testing was used to evaluate whether a statistically significant number of teams had experienced transitions. (Conover 1980)

In this case, statistical significance was assumed to be a simple majority (i.e., > 50%). The hypotheses H_0 and H_1 for this particular test are as follows:

H_0: $p \leq 0.50$

H_1: $p > 0.50$

The test statistic (T) was the number of teams determined to have experienced a transition. The test statistic was assumed to have a binomial distribution with parameters p and n (n = 353 for the short term teams and n = 41 for the long term teams).

Consequently, the rejection criteria was set at the integer just below n x p, where p = 0.50. If more than 176 short term teams experience transitions or more than 20 long term teams experience transitions, this would be significant evidence of the Punctuated Equilibrium Model's applicability in the science and engineering environment.

2. If science and engineering teams experience transitions, do the transitions occur at the temporal midpoints of their project timelines (H2)?

Miller (1997) liberally defined the temporal midpoint as the middle third of the temporal timeline and Miller's definition of the temporal midpoint was adopted for this study. With respect to the 50-point scale, the middle third would be 17.33 to 33.67.

The timing for transition-related questions that merited positive responses for a team were averaged and this averaged timing was assumed to be the timing of the team's transition, if in fact it was determined the team experienced a transition.

Of teams that experienced transitions, the number and percentage of teams that experienced their transitions at the temporal midpoint was determined. Hypothesis testing was utilized to determine if a statistically significant number of teams (i.e., a simple majority) experienced transitions at the temporal midpoint. (Conover 1980)

In this case, statistical significance was assumed to be a simple majority (i.e., > 50%). The hypotheses H_0 and H_1 for this particular test are as follows:

H_0: $p \leq 0.50$

H_1: $p > 0.50$

The test statistic was the number of teams determined to have experienced a transition at the temporal midpoint. The test statistic was assumed to have a binomial distribution with parameters p and n. If an even number of teams experienced transitions, the rejection criteria was set n x p, where n represents the number of teams that were determined to have experienced a transition and p = 0.50. If an odd number of teams experienced transitions, the rejection criteria was set at the integer just below n x p.

If a majority of short or long term teams that experience transitions experience those transitions at the temporal midpoint, this would be significant evidence of the Punctuated Equilibrium Model's applicability in the science and engineering environment.

3. Collectively, do teams that experience transitions perform better than teams that do not experience transitions (H3)?

Each team's performance was measured using the Halfhill (In Press) Business and Engineering Technology Survey. Hypothesis testing was used to compare the performance of teams that experienced a transition to the performance of teams that did not experience a transition (Hines and Montgomery 1990).

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2}$

Criteria for rejection: $|t_0| > t_{\alpha/2,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2$

4. Collectively, do teams that experience a transition at the temporal midpoint perform better than other teams (H4)?

Each team's performance was measured using the Halfhill (In Press) Business and Engineering Technology Survey. Hypothesis testing was used to compare the performance of teams that experienced a transition at the temporal midpoint to the performance of all other teams (Hines and Montgomery 1990).

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2}$

Criteria for rejection: $|t_0| > t_{\alpha/2, \nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2$

I. Summary

Data evaluated for this study was collected via the survey instrument method. Two surveys were used, the Group Process Questionnaire and the Halfhill Business and Engineering Technology Survey.

The data were filtered at the individual and team levels in order to ensure only quality data were being evaluated. The number of teams being evaluated was reduced from 490 to 394 in the filtering process.

With respect to the first hypothesis, the number/percentage of teams experiencing transitions was evaluated with respect to the first hypothesis using the 50.1% methodology. This methodology was selected from three general methodologies because of its ability to best balance Type I and type II error. Hypothesis testing was used to determine if the number/percentage of teams experiencing transitions was statistically significant.

With respect to the second hypothesis, the number/percentage of teams experiencing transitions at the temporal midpoint was evaluated with respect to the second hypothesis. Hypothesis testing was used to determine if the number/percentage of teams experiencing transitions at the temporal midpoint was statistically significant.

With respect to the third hypothesis, hypothesis testing was applied to determine if there was a significant difference between the performance of teams that experienced transitions and the performance of teams that did not experience transitions. Similarly, with respect to the fourth hypothesis, hypothesis testing was again applied to determine if there was a significant difference between the performance of teams that experienced transitions at the temporal midpoint and the performance of all other teams.

Finally, the results were collectively evaluated to determine if the Punctuated Equilibrium Model was applicable to science and engineering teams. The results will be discussed in Chapter Five.

CHAPTER V

DATA ANALYSES

A. Discussion of Data

In an effort to evaluate the applicability of the Punctuated Equilibrium Model to team development in science and engineering organizations, two samples of science and engineering teams were analyzed independently for the existence and timing of transitions. Gersick (1984) identified the transition as the critical element of the Punctuated Equilibrium Model. The transition is the key event that enables the team to move beyond its initial, relatively unproductive, framework and into a relatively productive framework that enables a successful outcome.

The first sample contained 41 long term teams (after filtering) in their natural or "real world" environment. The second sample contained 353 short term teams (after filtering) operating in a training environment. Both data samples were obtained via the survey instrument method, specifically utilizing a combination of the Group Process Questionnaire developed by Miller (1997) and the Halfhill Business and Engineering Technology Survey developed by Halfhill (In Press).

Benfield (2005) and Knight (2006), operating independently, used the Group Process Questionnaire (GPQ) to collect data in support their studies of the Tuckman

Model. Because of the nature of the Group Process Questionnaire, their efforts also harvested data pertaining to the Punctuated Equilibrium Model. However, prior to this study, the data pertaining to the Punctuated Equilibrium Model had not been analyzed.

In addition to the data collected via the Group Process Questionnaire, Benfield (2005) and Knight (2006) also solicited team performance data from all respondents using the Halfhill (In Press) Business and Engineering Technology Survey. This data was solicited for the purpose of evaluating the relationship between team performance and adherence to a specific team development model. With respect to Benfield (2005) and Knight (2006), the team developmental model in question was the Tuckman Model. Nevertheless, the performance data is completely independent of the team development model in question and may be used just as effectively with respect to the Punctuated Equilibrium Model.

B. Presence of the Punctuated Equilibrium Model

a. 50.1% Methodology

The selected analysis methodology described in the previous chapter was applied to each team in the two data samples in order to directly evaluate the existence of a transition and, indirectly, the applicability of the Punctuated Equilibrium Model to short and long term science and engineering teams.

i. Occurrence of a Transition

With the intent of addressing the first hypothesis (H1), each team was determined to have either experienced a transition or not. The first null hypothesis states, “Teams within science and engineering organizations do not experience a transition with

respect to their development, thereby discounting the applicability of the Punctuated Equilibrium Model to science and engineering organizations."

In order to declare a team experienced a transition, 50.1% or more of qualified respondent opportunities must have submitted positive responses, collectively. The number and percentage of teams within the sample experiencing transitions was noted and a non-statistical conclusion was reached.

With only 22 of 353 (or 6.2%) short term teams determined to have experienced a transition, it was concluded that the null hypothesis could not be rejected. Ultimately, the conclusion was validated via hypothesis testing, assuming $p = 0.50$ and a test statistic (T) of 22 for short term teams where $n = 353$ and the criteria for rejection was 176; $T = 22 < 176$ (Conover 1980).

With only 5 of 41 teams (or 12.2%) long term teams determined to have experienced a transition, it was concluded that the null hypothesis could not be rejected. Ultimately, the conclusion was validated via hypothesis testing, assuming $p = 0.50$ and $T = 5$ for long term teams where $n = 41$ and the criteria for rejection was 20; $T = 5 < 20$ (Conover 1980).

ii. Timing

With the intent of addressing the second hypothesis (H2), each team that experienced a transition was determined to have either experienced its transition at the temporal midpoint or not. The second null hypothesis states, "Teams that experience transitions do not experience them at the temporal midpoint, thereby discounting the applicability of the Punctuated Equilibrium Model to science and engineering organizations."

The temporal midpoint is liberally defined as the middle third of the project's timeline, or 17.33 to 33.67 on a scale of 1 to 50. For each sample, the number and percentage of teams with transitions occurring within the temporal midpoint was noted and a non-statistical conclusion was reached.

Of the short term teams that were determined to have experienced transitions via the 50.1% methodology, 16 (of 22) or 72.7% experienced those transitions at the temporal midpoint. These results may have been considered somewhat encouraging. However, of the long term teams determined to have experienced transitions via the 50.1% methodology, only 1 (of 5) or 20.0% experienced its transition at the temporal midpoint.

Ultimately, the conclusions were validated by hypothesis testing. The second alternate hypothesis states, "Teams that experience transitions do so at the temporal midpoint, thereby endorsing the applicability of the Punctuated Equilibrium Model to science and engineering organizations." Assuming $p = 0.50$ and $T = 16$ for short term teams and $T = 1$ for long term teams. The rejection criteria equaled 11 for short term teams and 2 for long term teams. With respect to short term teams, the second null hypothesis was rejected in favor of the second alternate hypothesis because $T = 16 > 11$. However, with respect to long term teams, the results failed to reject the second null hypothesis because $T = 1 < 2$ (Conover 1980).

The significant variation in timing results are a cause for consideration and raises some questions. Is it reasonable that short term teams would be more likely to experience transitions at the temporal midpoint? Is it easier for members of short term teams to accurately estimate a point on the timeline relative to the entire timeline?

Short term teams' temporal timelines are measured in hours or maybe days while long term teams' temporal timelines may be measured in months or even years. It could be that when the timeline is more compressed, the transition is more likely to occur at the temporal midpoint. All previous studies involved teams with relatively compressed timelines. The long term team data collected by Benfield (2005) and evaluated in this study is the first data collected from science and engineering teams in their normal work environment with respect to the Punctuated Equilibrium Model.

iii. Performance (Transition vs. No Transition)

For each sample, performance of teams that each experienced a transition was compared to the performance of teams that did not experience a transition. Hypothesis testing on means and variances was utilized for this purpose. (Hines and Montgomery 1990) No difference in performance was observed between the performance of either short or long term teams that experienced transitions and those teams that did not experience transitions.

Twenty-two (n_1) short term teams that were determined to have experienced transitions produced a mean score of 4.24 with a standard deviation of 0.53.
Three hundred thirty-one (n_2) short term teams that were determined not to have experienced transitions produced a mean score of 4.15 with a standard deviation of 0.43.

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 0.78$

Criteria for rejection: $|t_0| > t_{\alpha/2,\ \nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 23.08$

$|t_0| = 0.78 < t_{\alpha/2,\,\nu} = 2.1$ (Hines and Montgomery 1990, Table IV)

Fail to Reject

Five (n_1) long term teams that were determined to have experienced transitions produced a mean score of 4.29 with a standard deviation of 0.51.

Thirty-six (n_2) long term teams that were determined not to have experienced transitions produced a mean score of 4.14 with a standard deviation of 0.47.

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 0.66$

Criteria for rejection: $|t_0| > t_{\alpha/2,\,\nu}$ where, $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 5.43$

$|t_0| = 0.78 < t_{\alpha/2,\,\nu} = 2.5$ (Hines and Montgomery 1990, Table IV)

Fail to Reject

Consequently, the results failed to reject the third null hypothesis ($H3_0$), which states, “The existence of a transition has no affect on the performance of a science and engineering team, thereby discounting the applicability of the Punctuated Equilibrium Model to team development in science and engineering organizations.”

iv. Performance (Transition at the Temporal Midpoint vs. Other)

For each sample, the performance of teams that each experienced transition at their temporal midpoint was compared to the performance of all other teams in the sample. Hypothesis testing on means and variances was utilized for this purpose. (Hines & Montgomery 1990) No statistically significant difference in performance was

observed between the performance of either short or long term teams that experienced transitions at the temporal midpoint and all other teams.

Sixteen (n_1) short term teams that were determined to have experienced transitions at the temporal midpoint produced a mean score of 4.30 with a standard deviation of 0.34. Three hundred thirty-seven (n_2) short term teams that were determined not to have experienced transitions at the temporal midpoint produced a mean score of 4.15 with a standard deviation of 0.44.

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 1.69$

Criteria for rejection: $|t_0| > t_{\alpha/2,\,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 17.73$

$|t_0| = 1.69 < t_{\alpha/2,\,\nu} = 2.1$ (Hines and Montgomery 1990, Table IV)

Fail to Reject

The long term team that was determined to have experienced a transition at the temporal midpoint produced a performance score of 3.80. Forty long term teams that were determined not to have experienced transitions at the temporal midpoint produced a mean score of 4.17 with a standard deviation of 0.47. Without a standard deviation for teams experiencing a transition at the temporal midpoint, hypothesis testing could not be conducted. However, it is worthy of note that the performance score of the team that was determined to have experienced a transition at the temporal midpoint is within one standard deviation of the mean performance score of the teams that did not experience transitions at the temporal midpoint.

Consequently, the results failed to reject the fourth null hypothesis ($H4_0$), which states, “The existence of a transition at the temporal midpoint has no affect on the performance of a science and engineering team, thereby discounting the applicability of the Punctuated Equilibrium Model to team development in science and engineering organizations.” Table 5.1 summarizes the results for the 50.1% Methodology.

Table 5.1 50.1 % Methodology Results

			H1o	H2o	H3o	H4o
Short Term Teams			Fail to Reject	Rejected	Fail to Reject	Fail to Reject
Long Term Teams			Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject

The 50.1% methodology was chosen because it balanced Type I and Type II error the best among all of the methodologies considered. Nevertheless, it is interesting to note what results the other methodologies would have produced.

b. Miller’s Methodology

i. Occurrence of a Transition

Only 49 or 13.9% of short term teams experienced transitions per Miller’s Methodology. Since $T = 49 < 176$, the first null hypothesis would not have been rejected. With respect to long term teams, 4 or 9.8% of long term teams experienced transitions per Miller’s Methodology. Since $T = 4 < 20$, the first null hypothesis would not have been rejected for long term teams, either. These results are consistent with the results produced by the 50.1% Methodology.

ii. Timing

With respect to short term teams, 33 of 49 (67.4%) teams that experienced a transition experienced that transition at the temporal midpoint. Since $T = 33 > 24$, the second null hypothesis would have been rejected. With respect to long term teams, 1 of 4 (25.0%) teams that experienced a transition experienced that transition at the temporal midpoint. Since $T = 1 < 2$, the second null hypothesis would not have been rejected for long term teams. These results are consistent with the results produced by the 50.1% Methodology.

iii. Performance (Transition vs. No Transition)

Forty-nine short term teams that were determined to have experienced transitions produced a mean score of 4.17 with a standard deviation of 0.49.
Three hundred four short term teams that were determined not to have experienced transitions produced a mean score of 4.15 with a standard deviation of 0.43.

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 0.19$

Criteria for rejection: $|t_0| > t_{\alpha/2,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 60.99$

$|t_0| = 0.19 < t_{\alpha/2,\nu} = 2.0$ (Conover 1980, Table A3),

Fail to Reject

Four long term teams that were determined to have experienced transitions produced a mean score of 4.44 with a standard deviation of 0.47. Thirty-seven long term teams that were determined not to have experienced transitions produced a mean score of 4.12 with a standard deviation of 0.46.

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 1.26$

Criteria for rejection: $|t_0| > t_{\alpha/2,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 4.11$

$|t_0| = 1.26 < t_{\alpha/2,\nu} = 2.8$ (Hines and Montgomery 1990, Table IV)

Fail to Reject

Consequently, the results (impacted by Miller's Methodology for determining whether a transition occurred) would have failed to reject the third null hypothesis ($H3_0$), which states, "The existence of a transition has no affect on the performance of a science and engineering team, thereby discounting the applicability of the Punctuated Equilibrium Model to team development in science and engineering organizations." These results are consistent with the results produced by the 50.1% Methodology.

iv. Performance (Transition at the Temporal Midpoint vs. Other)

Thirty-three short term teams that were determined to have experienced transitions at the temporal midpoint produced a mean score of 4.23 with a standard deviation of 0.41. Three hundred twenty short term teams that were determined not to have experienced transitions at the temporal midpoint produced a mean score of 4.14 with a standard deviation of 0.49.

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 1.13$

Criteria for rejection: $|t_0| > t_{\alpha/2,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 42.49$

$|t_0| = 1.13 < t_{\alpha/2,\nu}, = 2.0$ (Hines and Montgomery 1990, Table IV)

Fail to Reject

The long term team that was determined to have experienced a transition at the temporal midpoint produced a score of 3.80. Long term teams that were determined not to have experienced transitions at the temporal midpoint produced a mean score of 4.05 with a standard deviation of 0.55. Since only one long term team was determined to have experienced a transition at the temporal midpoint, a standard deviation could not be calculated. Nevertheless, the performance score of the team that was determined to have experienced a transition was within one standard deviation of the mean performance score of the teams that were determined to have not experienced transitions.

Consequently, the results (impacted by Miller's Methodology for determining whether a transition occurred) failed to reject the fourth null hypothesis ($H4_0$), which states, "The existence of a transition at the temporal midpoint has no affect on the performance of a science and engineering team, thereby discounting the applicability of the Punctuated Equilibrium Model to team development in science and engineering organizations." These results are consistent with the results produced by the 50.1% Methodology. Table 5.2 summarizes the results for Miller's Methodology.

Table 5.2 Miller's Methodology Results

	H1o	H2o	H3o	H4o
Short Term Teams	Fail to Reject	Rejected	Fail to Reject	Fail to Reject
Long Term Teams	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject

c. Minimum Individual Positive Response (MIPR) - 1 Methodology

i. Occurrence of a Transition

Only 81 or 23.0% of short term teams experienced transitions per the MIPR-1 Methodology. Since $T = 81 < 176$, the first null hypothesis would not have been rejected. However, 22 or 53.7% of long term teams experienced transitions per the MIPR-1 Methodology. Since $T = 22 > 20$, the first null hypothesis would have been rejected.

The results associated with short term teams are consistent with the results produced by the 50.1% Methodology. However, the results associated with long term teams are inconsistent with the results produced by the 50.1% Methodology. It is important to keep in mind that MIPR-1 has a higher potential for Type I error.

ii. Timing

With respect to short term teams, 51 of 81 (63.0%) teams that experienced a transition experienced that transition at the temporal midpoint. Since $T = 51 > 40$, the second hypothesis would have been rejected. With respect to long term teams, 7 of 22 (31.8%) teams that experienced a transition experienced that transition at the temporal midpoint. Since $T = 7 < 11$, the second null hypothesis would not have been rejected for long term teams. The timing results associated with MIPR-1 for both short term teams and long term teams are consistent with the timing results produced by the 50.1% Methodology.

iii. Performance (Transition vs. No Transition)

Eighty-one short term teams that were determined to have experienced transitions produced a mean score of 4.16 with a standard deviation of 0.52.

Two hundred seventy-two short term teams that were determined not to have experienced transitions produced a mean score of 4.15 with a standard deviation of 0.42.

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 0.22$

Criteria for rejection: $|t_0| > t_{\alpha/2,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 112.99$

$|t_0| = 0.22 < t_{\alpha/2,\nu} = 2.0$ (Hines and Montgomery 1990, Table IV)

Fail to Reject

Twenty-two long term teams that were determined to have experienced transitions produced a mean score of 4.09 with a standard deviation of 0.64. Nineteen long term teams that were determined not to have experienced transitions produced a mean score of 4.23 with a standard deviation of 0.35.

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = -0.84$

Criteria for rejection: $|t_0| > t_{\alpha/2,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 34.73$

$|t_0| = 0.84 < t_{\alpha/2,\nu} = 2.0$ (Hines and Montgomery 1990, Table IV)

Fail to Reject

Consequently, the results (impacted by MIPR-1 for determining a whether transition occurred) would have failed to reject the third null hypothesis ($H3_0$), which states, “The existence of a transition has no affect on the performance of a science and engineering team, thereby discounting the applicability of the Punctuated Equilibrium

Model to team development in science and engineering organizations." These results are consistent with the results produced by the 50.1% Methodology.

iv. Performance (Transition at the Temporal Midpoint vs. Other)

Fifty-one short term teams that were determined to have experienced transitions at the temporal midpoint produced a mean score of 4.24 with a standard deviation of 0.43. Three hundred two short term teams that were determined not to have experienced transitions at the temporal midpoint produced a mean score of 4.10 with a standard deviation of 0.63.

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 1.92$

Criteria for rejection: $|t_0| > t_{\alpha/2,\,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 92.56$

$|t_0| = 1.92 < t_{\alpha/2,\,\nu} = 2.0$ (Hines and Montgomery 1990, Table IV)

Fail to Reject

Seven long term teams that were determined to have experienced transitions at the temporal midpoint produced a mean score of 4.13 with a standard deviation of 0.28. Thirty-four long term teams that were determined not to have experienced transitions at the temporal midpoint produced a mean score of 4.16 with a standard deviation of 0.50.

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 0.21$

Criteria for rejection: $|t_0| > t_{\alpha/2,\,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 18.37$

$|t_0| = 0.21 < t_{\alpha/2,\,\nu} = 2.1$ (Hines and Montgomery 1990, Table IV)

Fail to Reject

Consequently, the results (impacted by MIPR-1 for determining whether a transition occurred) failed to reject the fourth null hypothesis ($H4_0$), which states, "The existence of a transition at the temporal midpoint has no affect on the performance of a science and engineering team, thereby discounting the applicability of the Punctuated Equilibrium Model to team development in science and engineering organizations." These results are consistent with the results produced by the 50.1% Methodology. Table 5.3 summarizes the results for the MIPR-1 Methodology.

Table 5.3 MIPR-1 Methodology Results

	H1o	H2o	H3o	H4o
Short Term Teams	Fail to Reject	Rejected	Fail to Reject	Fail to Reject
Long Term Teams	Rejected	Fail to Reject	Fail to Reject	Fail to Reject

d. Minimum Individual Positive Response (MIPR) - 2 Methodology

i. Occurrence of a Transition

Only 10 or 2.8% of short term teams experienced transitions per the MIPR-2 Methodology. Since T = 10 < 176, the first null hypothesis would not have been rejected. Only 3 or 7.3% of long term teams experienced transitions per the MIPR-2 Methodology. Since T = 3 < 20, the first null hypothesis would have been rejected for long term teams as well. These results are consistent with the results produced by the 50.1% Methodology.

ii. Timing

With respect to short term teams, 2 of 10 (20.0%) teams that experienced a transition experienced that transition at the temporal midpoint. Since $T = 2 < 5$, the second hypothesis would not have been rejected. With respect to long term teams, none of the teams that experienced a transition experienced that transition at the temporal midpoint. Since $T = 0 < 1$, the second null hypothesis would not have been rejected.

The timing results associated with short term teams was inconsistent with the timing results produced by the 50.1% Methodology; however, the timing results associated with long term teams was consistent with the timing results produced by the 50.1% Methodology.

iii. Performance (Transition vs. No Transition)

Ten short term teams that were determined to have experienced transitions produced a mean score of 4.31 with a standard deviation of 0.44. Three hundred forty-three short term teams that were determined not to have experienced transitions produced a mean score of 4.15 with a standard deviation of 0.44.

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 1.15$

Criteria for rejection: $|t_0| > t_{\alpha/2,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 9.66$

$|t_0| = 1.15 < t_{\alpha/2,\nu} = 2.2$ (Hines and Montgomery 1990, Table IV)

Fail to Reject

Three long term teams that were determined to have experienced transitions produced a mean score of 4.40 with a standard deviation of 0.61. Thirty-eight long term

teams that were determined not to have experienced transitions produced a mean score of 4.14 with a standard deviation of 0.46.

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 0.72$

Criteria for rejection: $|t_0| > t_{\alpha/2,\,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 2.37$

$|t_0| = 0.72 < t_{\alpha/2,\,\nu} = 4.3$ (Hines and Montgomery 1990, Table IV)

Fail to Reject

Consequently, the results (impacted by MIPR-2 for determining whether a transition occurred) would have failed to reject the third null hypothesis ($H3_0$), which states, “The existence of a transition has no affect on the performance of a science and engineering team, thereby discounting the applicability of the Punctuated Equilibrium Model to team development in science and engineering organizations.” These results are consistent with the results produced by the 50.1% Methodology.

iv. Performance (Transition at the Temporal Midpoint vs. Other)

Two short term teams that were determined to have experienced transitions at the temporal midpoint produced a mean score of 4.30 with a standard deviation of 0.42. Three hundred fifty-one short term teams that were determined not to have experienced transitions at the temporal midpoint produced a mean score of 4.05 with a standard deviation of 0.76.

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 0.81$

Criteria for rejection: $|t_0| > t_{\alpha/2,\,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 1.11$

$|t_0| = 0.81 < t_{\alpha/2,\nu} = 12.7$ (Hines and Montgomery 1990, Table IV)

Fail to Reject

No long term teams were determined to have experienced transitions at the temporal midpoint. Consequently, no comparison could be made between the performance of those teams that experienced transitions at the temporal midpoint and all other teams.

With respect to short term teams, the results (impacted by MIPR-2 for determining whether a transition occurred) failed to reject the fourth null hypothesis ($H4_0$), which states, "The existence of a transition at the temporal midpoint has no affect on the performance of a science and engineering team, thereby discounting the applicability of the Punctuated Equilibrium Model to team development in science and engineering organizations." The results associated with short term teams are consistent with the results produced by the 50.1% Methodology.

Table 5.4 MIPR-2 Methodology Results

		H1o	H2o	H3o	H4o
Short Term Teams		Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject
Long Term Teams		Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject

e. Minimum Individual Positive Response (MIPR) - 3 Methodology

i. Occurrence of a Transition

Only 1 or 0.3% of short term teams experienced transitions per the MIPR-3 Methodology. Since T = 1 < 176, the first null hypothesis would not have been rejected.

Only 2 or 4.9% of long term teams experienced transitions per the MIPR-3 Methodology. Since T = 2 < 20, the first null hypothesis would not have been rejected. Although these results are consistent with the results produced by the 50.1% Methodology, it is important to note that the MIPR-3 Methodology favors Type II error.

ii. Timing

With respect to short term teams, the team that experienced a transition did not experience that transition at the temporal midpoint. Consequently, the second hypothesis would not have been rejected. With respect to long term teams, neither team that experienced a transition experienced that transition at the temporal midpoint. Consequently, the second null hypothesis would not have been rejected.

The timing results associated with short term teams was inconsistent with the timing results produced by the 50.1% Methodology; however, the timing results associated with long term teams was consistent with the timing results produced by the 50.1% Methodology.

iii. Performance (Transition vs. No Transition)

The only short term team that was determined to have experienced a transition produced a score of 3.65. Three hundred fifty-two short term teams that were determined not to have experienced transitions produced a mean score of 4.14 with a standard deviation of 0.49. Since only one short term team was determined to have experienced a transition, a standard deviation could not be calculated. Nevertheless, it is worthy of note that the performance score of the team that was determined to have experienced a transition was within one standard deviation of the mean performance score of the teams that were determined to have not experienced transitions.

Two long term teams that were determined to have experienced transitions produced a mean score of 4.73 with a standard deviation of 0.28. Thirty-nine long term teams that were determined not to have experienced transitions produced a mean score of 4.12 with a standard deviation of 0.46.

H_0: $\mu_1 = \mu_{2;}$ $H_{1:}$ $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 2.84$

Criteria for rejection: $|t_0| > t_{\alpha/2,\,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 1.86$

$|t_0| = 2.84 < t_{\alpha/2,\,\nu} = 4.3$ (Hines and Montgomery 1990, Table IV)

Fail to Reject

Consequently, the results (impacted by the MIPR-3 Methodology for determining whether a transition occurred) would have failed to reject the third null hypothesis ($H3_0$), which states, "The existence of a transition has no affect on the performance of a science and engineering team, thereby discounting the applicability of the Punctuated Equilibrium Model to team development in science and engineering organizations." These results are consistent with the results produced by the 50.1% Methodology.

iv. Performance (Transition at the Temporal Midpoint vs. Other)

No short or long term teams were determined to have experienced transitions at the temporal midpoint. Consequently, no comparison could be made between the performance of those teams that experienced transitions at the temporal midpoint and all other teams.

Table 5.5 MIPR-3 Methodology Results

	H1o	H2o	H3o	H4o
Short Term Teams	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject
Long Term Teams	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject

C. Summary

Two samples of science and engineering teams were evaluated within this study. One sample contained 353 short term teams (filtered from 368 teams) in a training environment, and the other sample contained 41 long term teams (filtered from 122 teams) in their natural working environment. Utilizing non-statistical methods (i.e., evaluating percentages), it was determined that a small percentage of science and engineering teams experience transitions; 6.7% and 12.2% for short term and long term teams, respectively. Ultimately, hypothesis testing was used to determine that the first null hypothesis ($H1_0$), which states, “Teams within science and engineering organizations do not experience a transition with respect to their development, thereby discounting the applicability of the Punctuated Equilibrium Model to science and engineering organizations,” could not be rejected.

These results (i.e., the relative lack of transitions) might have been enough to discount the applicability of the Punctuated Equilibrium Model to science and engineering teams; however, at this point, the possibility still existed that relatively few teams experiencing transitions or transitions at the temporal midpoint might be outperforming those teams that did not experience transitions or transitions at the temporal midpoint.

Of the short term teams that did experience transitions, a significant percentage (72.7%) experienced their transitions at the temporal midpoint. In this case, the second null hypothesis, which states, “Teams that experience transitions do so uniformly along the timeline, thereby discounting the applicability of the Punctuated Equilibrium Model to science and engineering organizations,” was rejected for short term teams. However, of those long term teams that experienced transitions, a relatively small percentage of teams (40.0%) experienced their transitions at the temporal midpoint. Consequently, the results for long term teams failed to reject the second null hypothesis ($H2_0$).

With respect to performance in both short and long term teams, there appeared to be no statistically significant difference in those teams that experienced transitions versus those teams that did not experience transitions. Consequently, the results failed to reject the third null hypothesis ($H3_0$), which states, “The existence of a transition has no affect on the performance of a science and engineering team, thereby discounting the applicability of the Punctuated Equilibrium Model to team development in science and engineering organizations.”

Again, with respect to performance in both short and long term teams, there appeared to be no statistically significant difference in those teams that experienced transitions at the temporal midpoint versus all other teams. Consequently, the results failed to reject the fourth null hypothesis ($H4_0$), which states, “The existence of a transition at the temporal midpoint has no affect on the performance of a science and engineering team, thereby discounting the applicability of the Punctuated Equilibrium Model to team development in science and engineering organizations.”

Having rejected all four null hypotheses with respect to long term teams and all but the second null hypothesis with respect to short term teams, it was determined the Punctuated Equilibrium Model does not appear to have significant applicability with respect to science and engineering teams. A small percentage of teams appear to experience transitions and, within long term teams, a small percentage of those transitions appear to occur at the temporal midpoint. It is true that transitions that occur within short term teams appear more likely to occur at the temporal midpoint. However, with respect to both short and long term teams, team performance did not appear to be related to either the occurrence or timing of transitions.

Other methodologies, if chosen, would have produced similar results as compared to the 50.1% methodology, even though they were less balanced in terms of Type I and Type II error, the basis upon which the 50.1% Methodology was chosen.

As illustrated in the Table 5.6, Consolidated Hypothesis Testing Results – Short Term Teams, three of the five methodologies evaluated would have rejected the second null hypothesis, including the 50.1% Methodology. With respect to the other three hypotheses, all methodologies produced consistent results.

Table 5.6 Hypothesis Testing Results – Short Term Teams

		50.1%	MIPR-1	MIPR-2	MIPR-3	MM
% Transitions	$H1_0$	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject
% @ Calendar Midpoint	$H2_0$	Rejected	Rejected	Fail to Reject	Fail to Reject	Rejected
Performance Difference	$H3_0$	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject
Performance Difference	$H4_0$	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject

As illustrated in the Table 5.7, Consolidated Hypothesis Testing Results – Long Term Teams, the MIPR-1 Methodology produced the only exception, rejecting the first null hypothesis. With respect to the other three hypotheses, all methodologies produced consistent results.

Table 5.7 Hypothesis Testing Results – Long Term Teams

		50.1%	MIPR-1	MIPR-2	MIPR-3	MM
% Transitions	$H1_0$	Fail to Reject	Rejected	Fail to Reject	Fail to Reject	Fail to Reject
% @ Calendar Midpoint	$H2_0$	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject
Performance Difference	$H3_0$	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject
Performance Difference	$H4_0$	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject	Fail to Reject

Regardless of the methodology chosen to determine whether a team experienced a transition, a relatively small number of teams experienced transitions. The one possible exception being that the MIPR-1 methodology requiring only one positive observation per team member did produce results showing the majority (53.7%) of long term teams saw a transition. Nevertheless, the MIPR-1 methodology was not chosen and for good reason. The MIPR-1 methodology favors Type I error, especially for teams with 15 or fewer respondents (See Chapter 4 and Appendix C).

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

A. Findings

The Punctuated Equilibrium Model does not appear to have significant applicability with respect to team development in science and engineering organizations. According to Gersick, the author of the Punctuated Equilibrium Model, a successful team should experience a transition at its temporal midpoint. However, only a small percentage of both short (6.7%) and long term (12.2%) science and engineering teams appear to experience transitions and, with respect to long term teams, a small percentage (40.0%) of those transitions appear to occur at the temporal midpoint.

Relative to long term teams, short term teams appear much more likely to experience transitions at their temporal midpoints. Of the short term teams that experienced transitions, 72% experienced those transitions at their temporal midpoints. This is an important observation, but it would be much more important if a majority of short term teams had experienced transitions or if team performance could have been linked to either the occurrence or timing of transitions, which was not the case. Also, it should be kept in mind that, for this research, the definition of the temporal midpoint was fairly liberal, including the middle one-third of the project's timeline.

In addition, team performance did not appear to be related to either the occurrence or timing of transitions. No statistically significant difference in performance was found between (either short or long term) teams that experienced transitions and teams that did not experience transitions. Furthermore, no statistically significant difference in performance was found between (either short or long term) teams that experienced transitions at the temporal midpoint and all other teams.

Lacking evidence that either short or long term science and engineering teams experience transitions, recognizing that transitions that occur in long term teams rarely occur at the temporal midpoint, and observing no relationship between either the occurrence or timing of transitions and team performance (in either short or long term teams) leads to the logical conclusion that the Punctuated Equilibrium Model appears to lack applicability with respect to science and engineering teams.

The results of this study appear to be somewhat consistent with the results of the studies conducted by Seers and Woodruff (1997). Although they did not study science and engineering teams, they found a lack of applicability with respect to undergraduate management students.

It should be noted that when selecting a methodology for evaluating the data to determine if a transition occurred, Type I and Type II error were allowed to balance. This was a liberal approach that enabled a favorable evaluation of the Punctuated Equilibrium Model. Typically, in hypothesis testing, α is set to a low value such as 0.5 (to mitigate the risk of Type I error) and an overwhelming amount of evidence is required to reject the null hypothesis.

Also, the temporal midpoint was defined as the middle third of the timeline. This was a liberal definition that further enabled a favorable evaluation of the Punctuation Equilibrium Model.

B. Observations

Although the Punctuated Equilibrium Model may not be directly applicable to team development in science and engineering organizations, there may be more to learn regarding the particular aspects of this team development model or, more importantly, this type of team development model. Although Gersick emphasized the transition as the critical element of the Punctuated Equilibrium Model, she also identified other constructs, including four elements of team development behavior and four factors of team development.

The four elements of team development behavior identified by Gersick (1984) were Task Definition, Choice of Direction, Construction, and Evaluation. They were defined as follows.

Task Definition: The team comes to some agreement about its task. This means reaching agreement, at least minimally, with respect to the content of their assignment.

Choice of Direction: Given a task, the team chooses how to go about accomplishing it. This calls for agreement on the direction to take. Two different processes were observed. One team initially chose a method, or work strategy that they expected would lead them to a solution. Other groups focused initially on choosing a particular solution to be constructed, with the method or strategy following implicitly from that choice.

Construction: This is the activity by which the team's intentions are materialized. This means building up and elaborating a body of ideas that the members agreed to include in their products.

Evaluation: Once the product had been constructed, it can be evaluated. Every group in her sample followed up its construction work with a period of critical evaluation, measuring their drafts against the criteria that they perceived would be used by audiences or users external to the group.

If teams tended to address these four elements in order, the result could be interpreted as the stages of a hierarchical model. It is interesting that the Punctuated Equilibrium Model contains all the elements of a hierarchical model, which means that Gersick's (1984) research is somewhat consistent with the research conducted by Tuckman and others. However, it is important to remember that the Tuckman group development model, a hierarchical model, was also challenged with respect to its applicability to team development in science and engineering organizations (Benfield 2005) (Knight 2006).

Even though this current study discounts the theory that science and engineering teams experience a paradigmatic shift, it neither confirms nor disavows the multi-sequence nature of team development with respect to science and engineering teams. A multi-sequence model may still be more effective than a stage-based model, or a hybrid model may be better than either type of model (hierarchical or multi-sequence) used alone.

In addition to the four elements of team behavior, Gersick (1984) identified four team development factors that interacted to drive the transition. They were Task

Understanding, Time Pressure, Internal Group Dynamics, and External Influence, and they were defined as follows:

Task Understanding: The team needs to understand, collectively, the assigned task at hand. As fundamental as it sounds, teams may and frequently begin without a clear understanding of the task.

Time Pressure: The second team development factor identified by Gersick (1984), time pressure, can affect individuals in different ways. Some individuals may perform better under pressure while others may not. When building a team, how does this factor affect the team, collectively? When recruiting team members, it may be best to recruit some members who can help the team deal effectively with time pressure while recognizing that not all members will be able to do so. Other members may have other critical skills that will contribute to the team's overall success. An effective mix of individuals may be an important element of an effective team.

Internal Group Dynamics: Although an important consideration with respect to any team development model, internal group dynamics were not a focus of this study. One survey collected data regarding the occurrence and timing of transitions while the other collected data regarding team-level performance. The interactions between individual members were not analyzed. This may be a weakness of the survey instrument method or, alternatively, an advantage of the observational method used by Gersick and others. Then again, it could be a weakness of the specific survey instruments chosen to collect the data analyzed for this study.

External Influence: External influence may be related to task understanding as previously stated. It is logical to think that leadership and management styles probably

affect team performance and, although the impact of a variety of styles should be mitigated across a large data sample, it could be that a particular style dominates the science and engineering realm. For example, an autocratic leadership and management style could hinder creativity. This study did not capture information regarding leadership and management styles of task delegators and there could be a style that dominates in the science and engineering environment.

As these factors were not directly evaluated (as constructs) in this study, more research may be needed to understand how these four factors may affect team development in science and engineering organizations. In particular, it would be beneficial to understand how these factors drive teams to address specific elements of team behavior.

Although the Punctuated Equilibrium Model does not appear to be applicable to science and engineering teams, there is no reason to believe, for example, that a lower level of task understanding would help in the team development process. On the surface, it seems foolish to think that a lesser understanding of the task would result in better team performance. Then again, perhaps task delegators could limit creativity by defining the task too clearly (i.e. dictating a path, maybe even an infeasible path, without allowing the team the freedom to find the optimal path to success).

C. Recommendations for Managers

Much has been written about leadership, management, and team development. Engineering managers, team leaders, and team members attempting to increase their knowledge of the team development process through research of the literature may come

across the Punctuated Equilibrium Model in their search to better understand what drives some teams to be more effective than others. If so, they may come to believe that a transition is necessary to achieve a successful outcome. However, the results of this study would indicate otherwise.

Engineering managers and team leaders in science and engineering organizations may take away from this study the knowledge that a successful team does not need to experience a transition at its temporal midpoint or, for that matter, a transition at any point along its timeline in order to be successful. This study has shown that there is no significant difference in performance between those science and engineering (short or long term) teams that do experience a transition and those that do not experience a transition.

However, with respect to the elements of team behavior identified by Gersick (1984) as well as their relationship to the factors of team development also identified by Gersick (1984), this study does not discount those observations. If that relationship could be better understood, it may be that engineering managers, team leaders, and team members could use that knowledge to more consistently lead their teams to successful outcomes, with or without transitions.

D. Recommendations for Further Study

1. Understanding the relationship between the elements of team development behavior and the factors of team development observed by Gersick (1984) would be very beneficial and a significant step toward creating the ideal team development model.

Future research of the Punctuated Equilibrium Model should be sensitive to those observations in addition to the occurrence, timing, and effect of transitional behavior.

2. It may be of benefit to evaluate varying definitions of the temporal midpoint. A fairly liberal definition of the temporal midpoint (middle third) was used for this study and it may not be productive to increase the size of the temporal midpoint beyond the middle third. However, it would be interesting to see how much the temporal midpoint can be reduced before a minority of short term team transitions are determined to occur at the temporal midpoint.

3. Since most prior studies of the Punctuated Equilibrium Model were conducted using the observation-based method, including both studies conducted by Gersick (1984, 1988, 1989), it may be useful to conduct another study of science and engineering teams using both the observation-based method as well as the survey-based method.

Durham (2008) applied the observation-based method to science and engineering undergraduate students and this dissertation applies the survey-based method to naturally occurring teams as well as teams of experienced employees in a training environment. The results appear to be inconsistent.

It would be interesting to repeat Durham's (2008) observational-styled experiment with student teams, but add the survey-based component. By evaluating the results from the two different methods on the same data set, it might be possible to gleam additional information that would be beneficial to the overall pursuit of an ideal team development model.

APPENDICES

APPENDIX A

SURVEY INSTRUMENT QUESTIONS

A.1 GROUP PROCESS QUESTIONNAIRE

1. Work went through a period of major change
2. A new approach quickly crystallized
3. New agreements were made about the direction to take the work
4. There was a noticeable change in strategy
5. The group abandoned their old approach and made a fresh start

The respondent indicates agreement or disagreement with the statement and, if the response is agreement, the respondent is further asked to indicate when the behavior occurred on a project timeline of 1 to 50.

A.2 HALFHILL PERFORMANCE MEASURE

1. This group understands how to accomplish its tasks.
2. This group is very good at planning how to accomplish their work objectives.
3. This group meets all objectives for work completed.
4. This group's work is always of the highest quality.
5. This group takes initiative in solving problems and decision making.

Each respondent is asked to rate each statement qualitatively using one of five adjectives, each of which is converted to a numerical score:

Strongly Agree	5
Agree	4
Neutral	3
Disagree	2
Strongly Disagree	1

In Chapter V, Data Analyses, all responses are averaged to get a team performance score. In Appendix D, the individual responses are summed and subsequently averaged to get a team performance score.

APPENDIX B

SURVEY INSTRUMENT APPROVAL LETTERS

APPENDIX B.1 GPQ USE APPROVAL

University of
Lethbridge

Faculty of Management

May 3, 2004

Michael P.J. Benfield
158 Stone Meadow Lane
Madison, AL 35758

Dear ~~Mr. Benfield~~ PJ.,

Regarding your inquiry for permission to use the Group Process Questionnaire, please feel free to use the questionnaire or any items therein for your research. I also understand that other faculty or students may also wish to employ the questionnaire. I am very happy to have others testing and making use of the items, so for any other interested persons, go ahead and use the questionnaire.

Sincerely,

Diane

Diane L. Miller (Ph.D.)
Associate Professor

APPENDIX B.2: PERFORMANCE MEASURE USE APPROVAL

Michael P.J. Benfield
158 Stone Meadow Lane
Madison, AL 35758

Mike,

The purpose of this letter is to formally state that you and your entire department may use any of the performance measures used in the Auburn BET project. Also, since the measures are published (in-press) they are considered public domain and available for public use.

If you have any questions please do not hesitate to contact me.

Sincerely,

Terry Hamhill

(724) 334-6715

APPENDIX C

TYPE I/TYPE II ERROR BY TEAM SIZE & METHODOLOGY

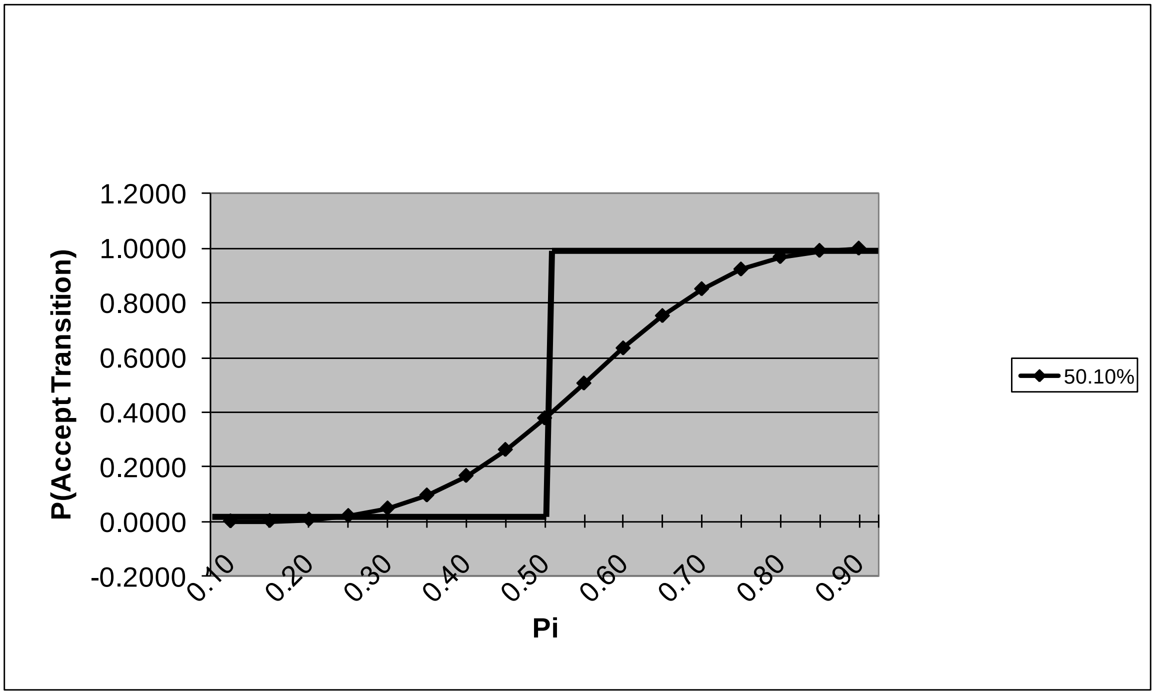


Figure C.1 50.1% Methodology with Two Respondents (α = 0.38 and β ≤ 0.62)

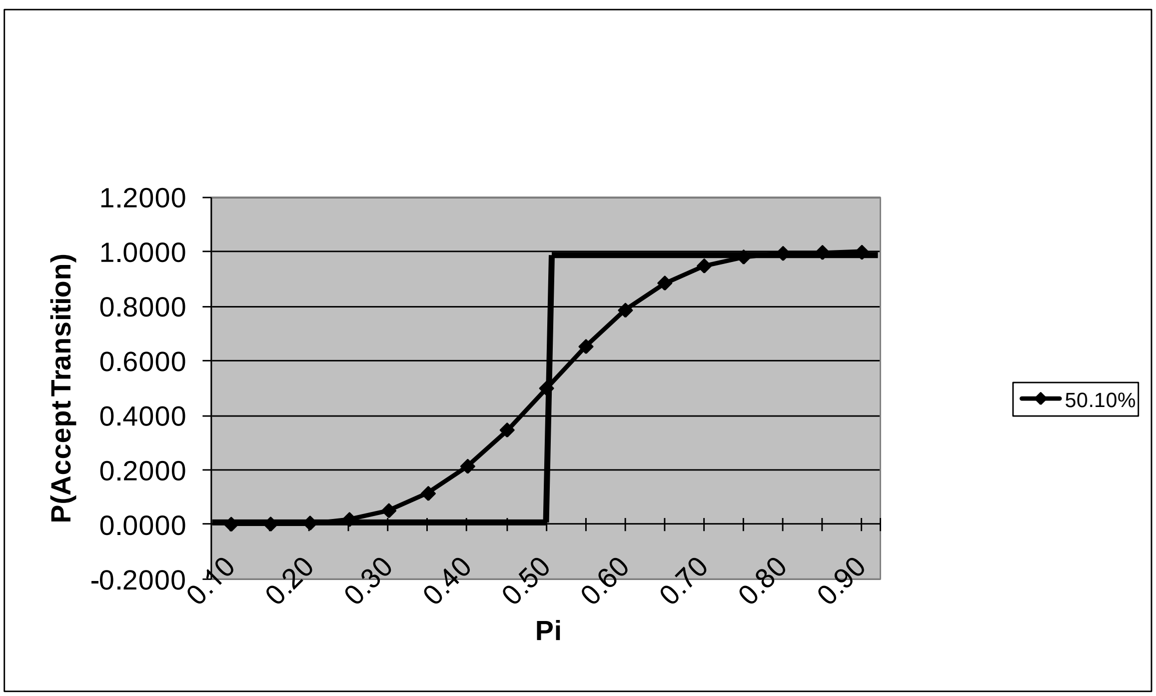


Figure C.2 50.1% Methodology with Three Respondents (α = 0.50 and β ≤ 0.50)

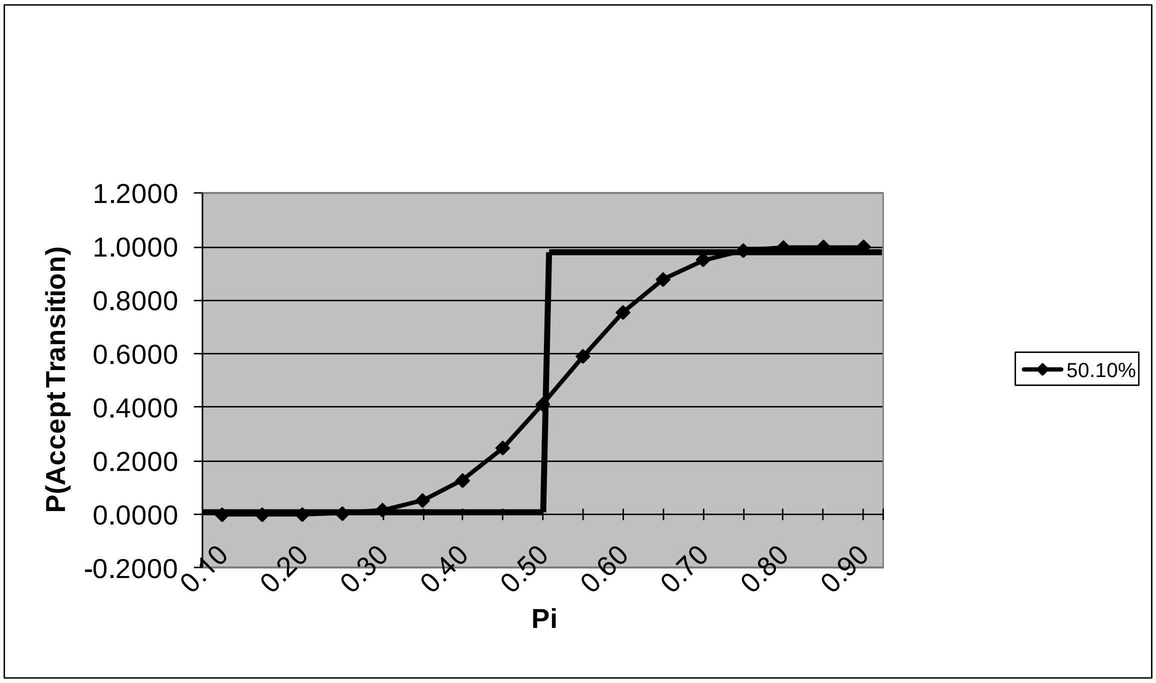


Figure C.3 50.1% Methodology with Four Respondents (α = 0.41 and β ≤ 0.59)

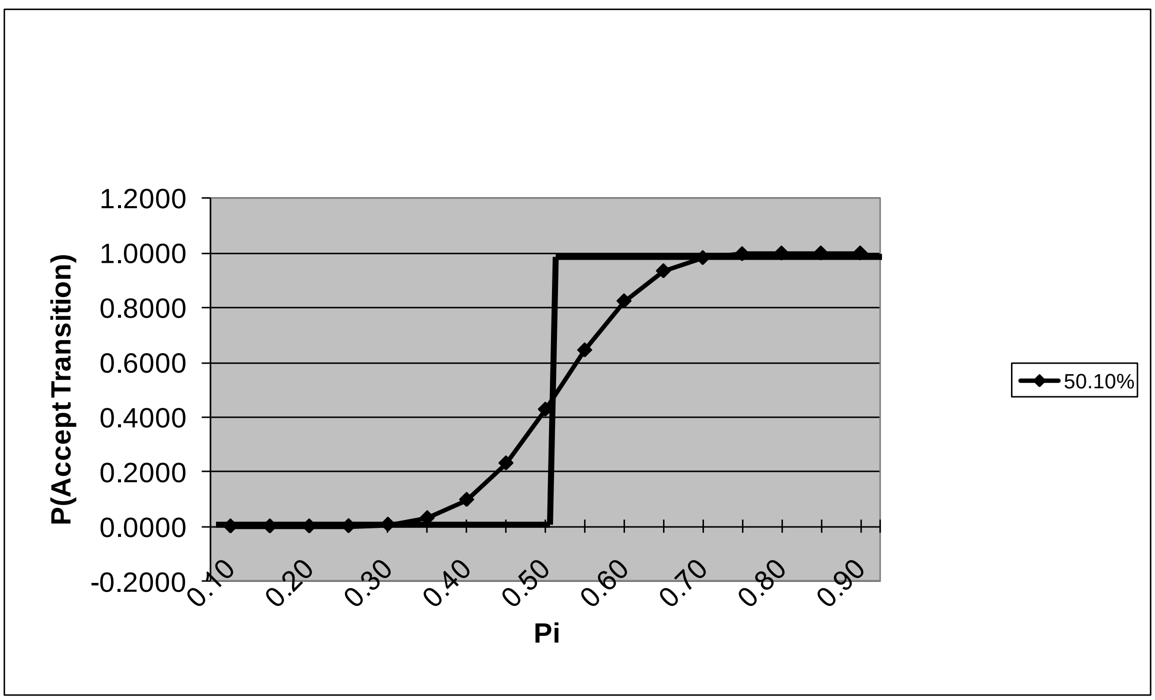


Figure C.4 50.1% Methodology with Six Respondents (α = 0.43 and β ≤ 0.57)

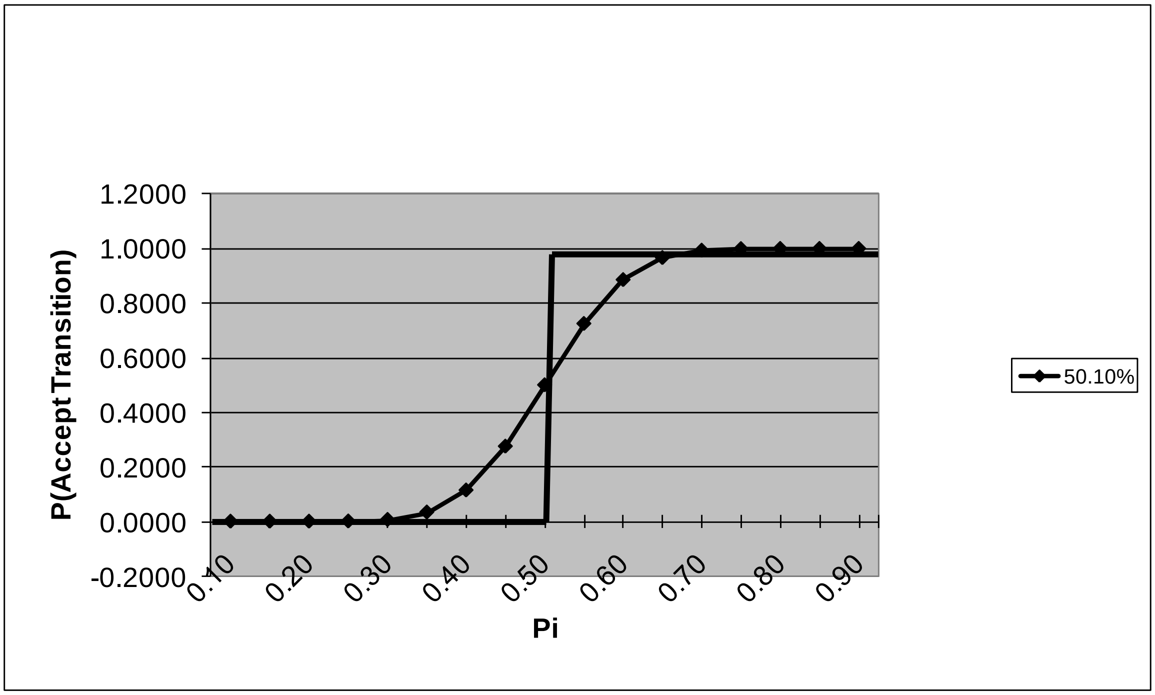


Figure C.5 50.1% Methodology with Seven Respondents (α = 0.50 and β ≤ 0.50)

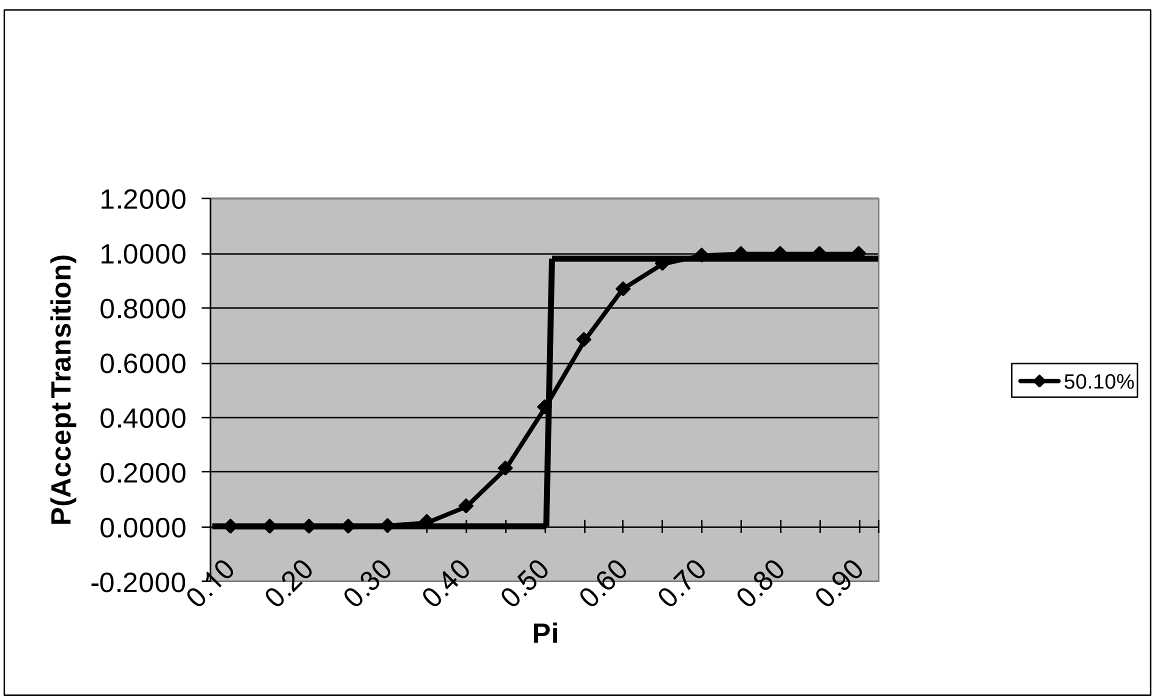


Figure C.6 50.1% Methodology with Eight Respondents (α = 0.44 and β ≤ 0.56)

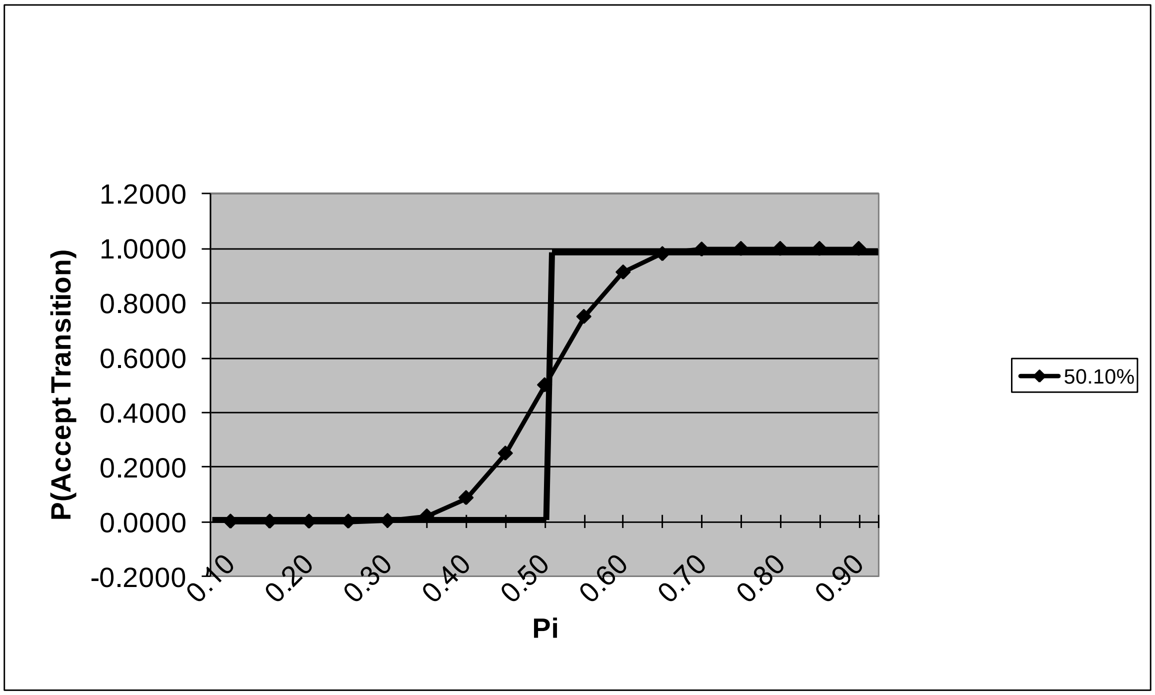


Figure C.7 50.1% Methodology with Nine Respondents (α = 0.50 and β ≤ 0.50)

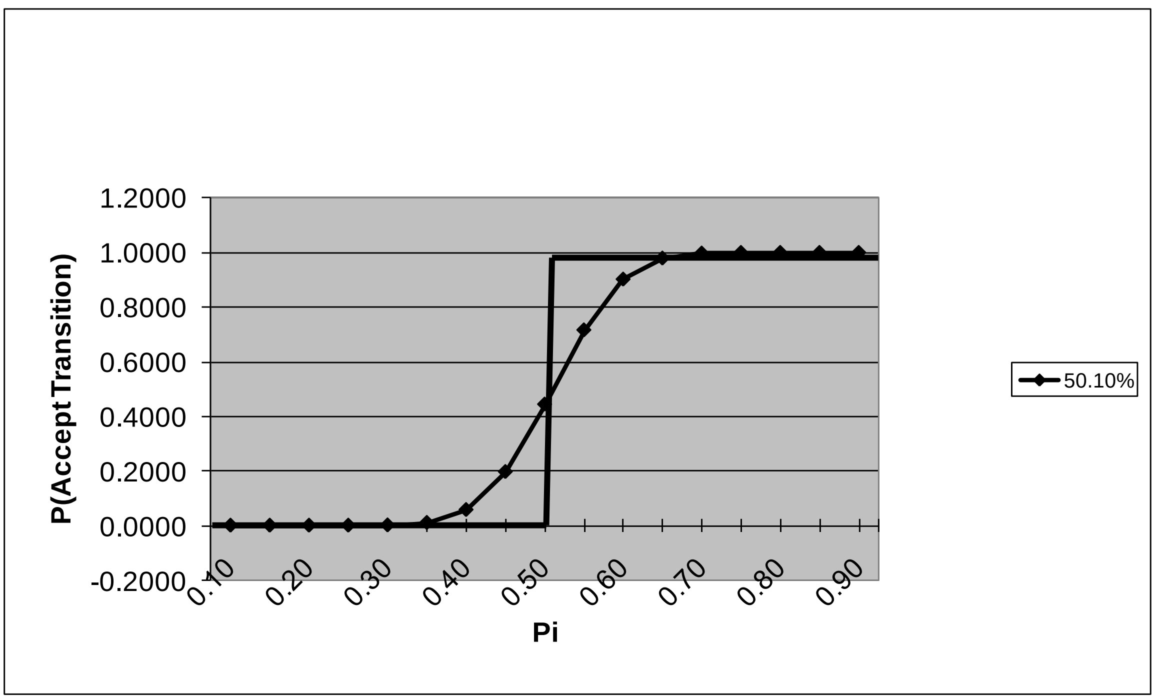


Figure C.8 50.1% Methodology with Ten Respondents (α = 0.44 and β ≤ 0.56)

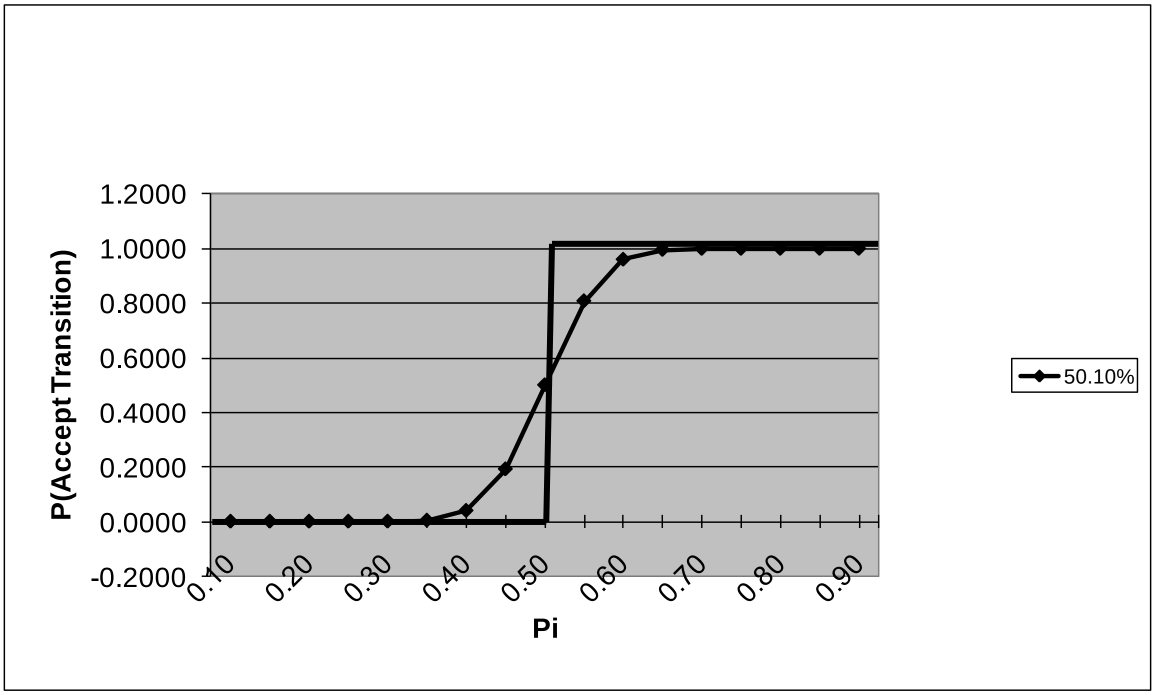


Figure C.9 50.1% Methodology with Fifteen Respondents ($\alpha = 0.50$ and $\beta \leq 0.50$)

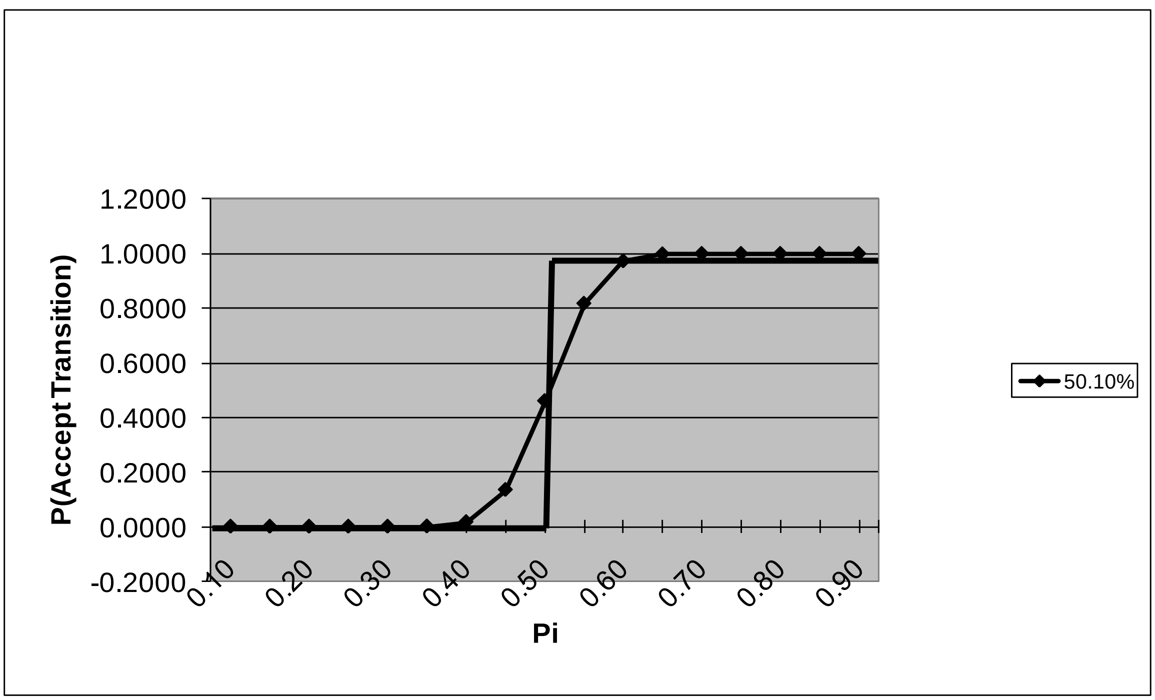


Figure C.10 50.1% Methodology with Twenty Respondents ($\alpha = 0.46$ and $\beta \leq 0.54$)

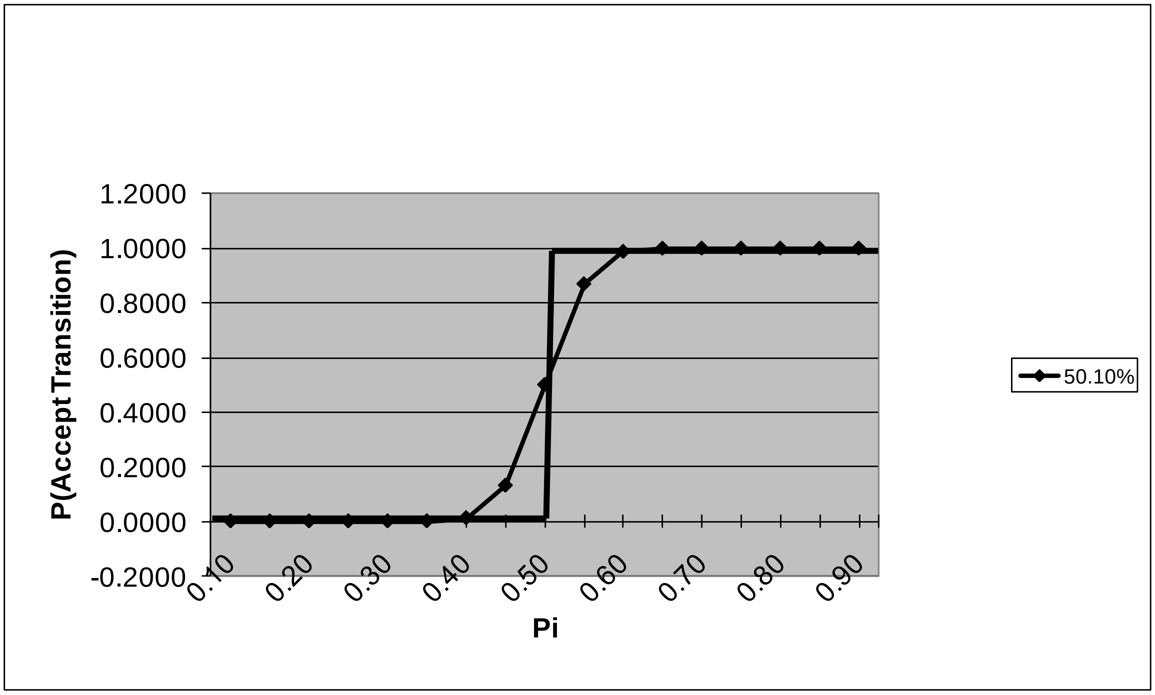


Figure C.11 50.1% Methodology with Twenty-Five Respondents (α = 0.50 and β ≤ 0.50)

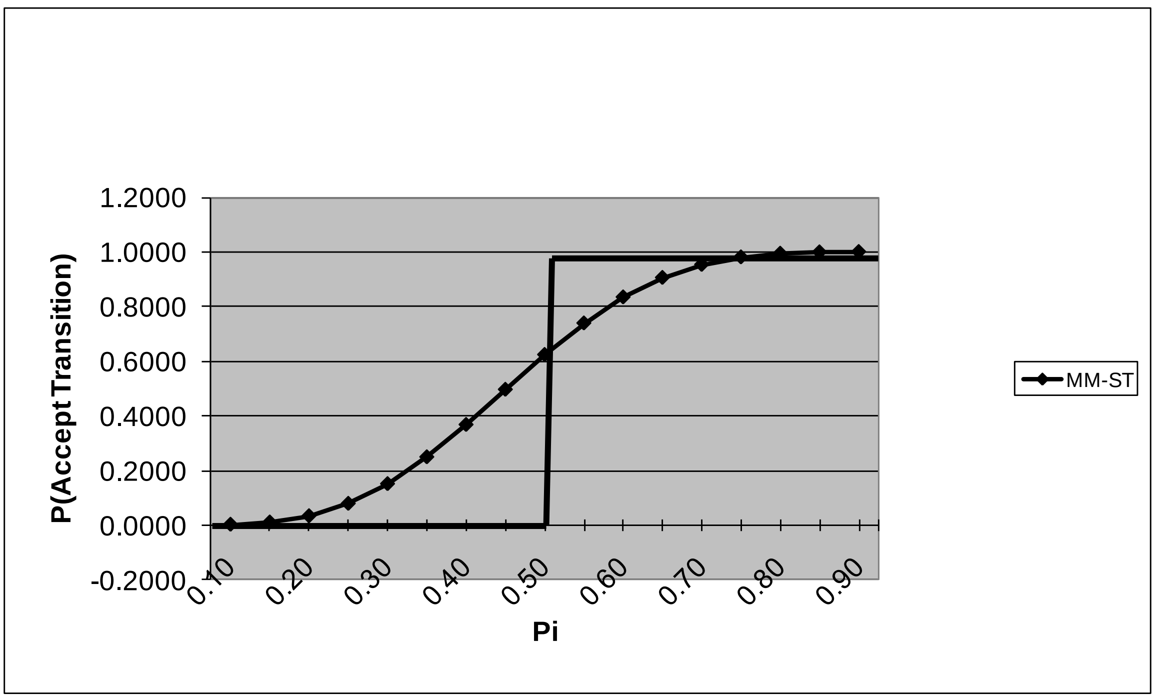


Figure C.12 MM-ST with Two Respondents (α = 0.62 and β ≤ 0.38)

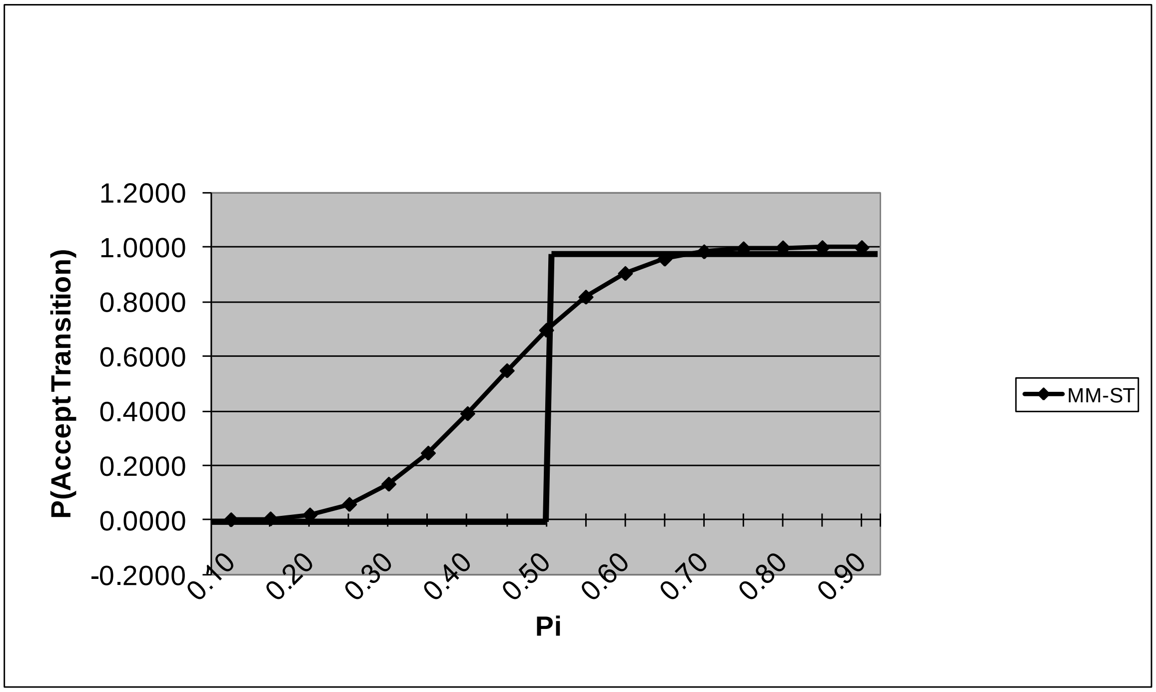


Figure C.13 MM-ST with Three Respondents (α = 0.70 and β ≤ 0.30)

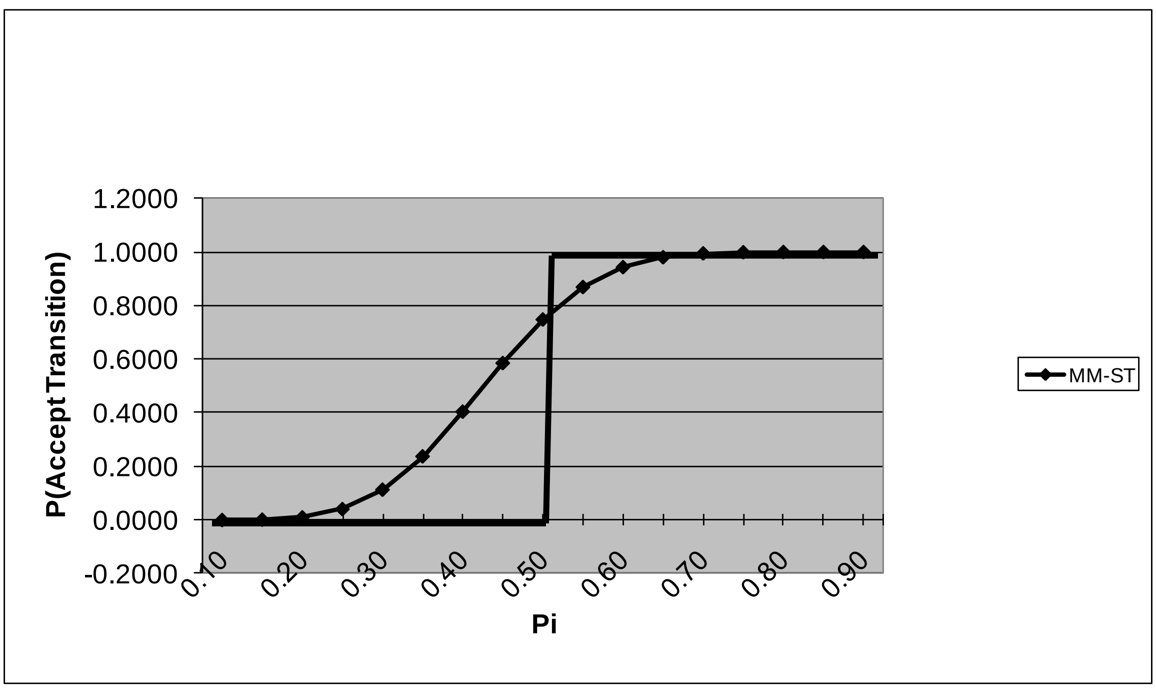


Figure C.14 MM-ST with Four Respondents (α = 0.75 and β ≤ 0.25)

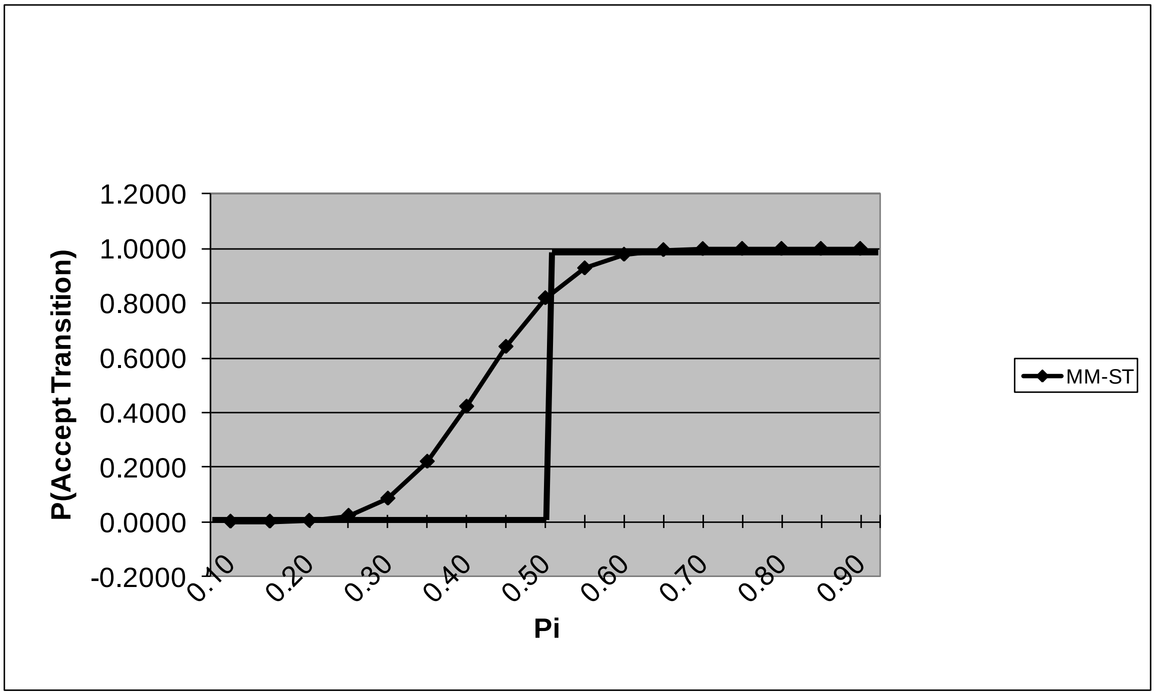


Figure C.15 MM-ST with Six Respondents ($\alpha = 0.82$ and $\beta \leq 0.18$)

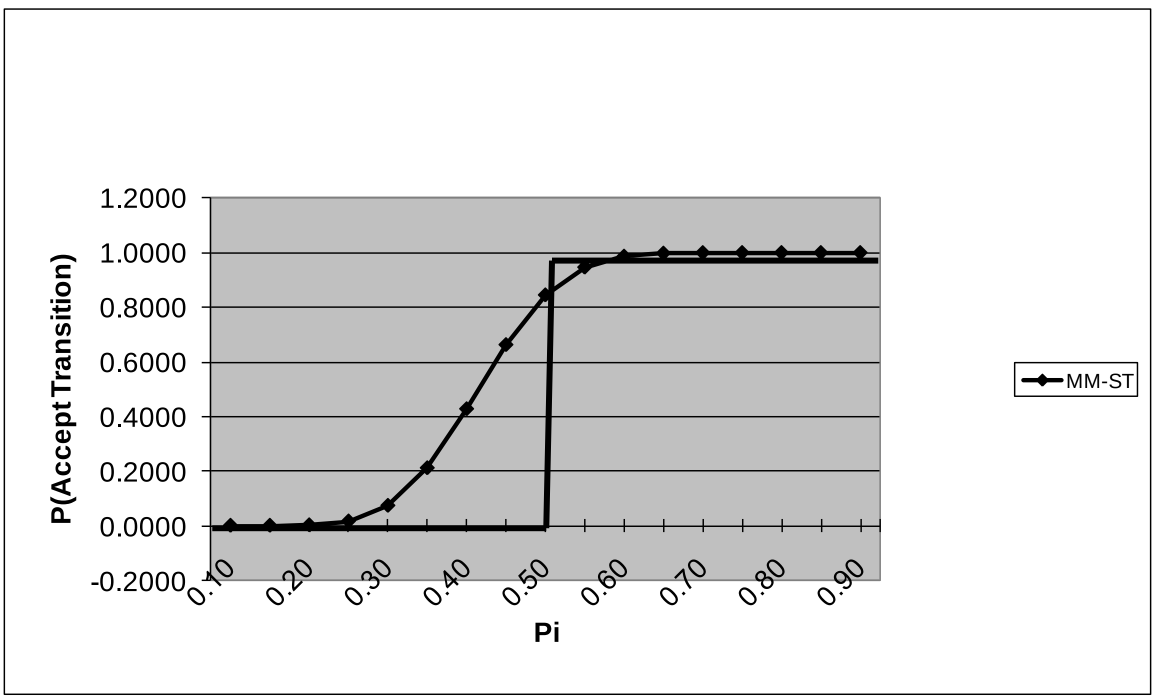


Figure C.16 MM-ST with Seven Respondents ($\alpha = 0.84$ and $\beta \leq 0.16$)

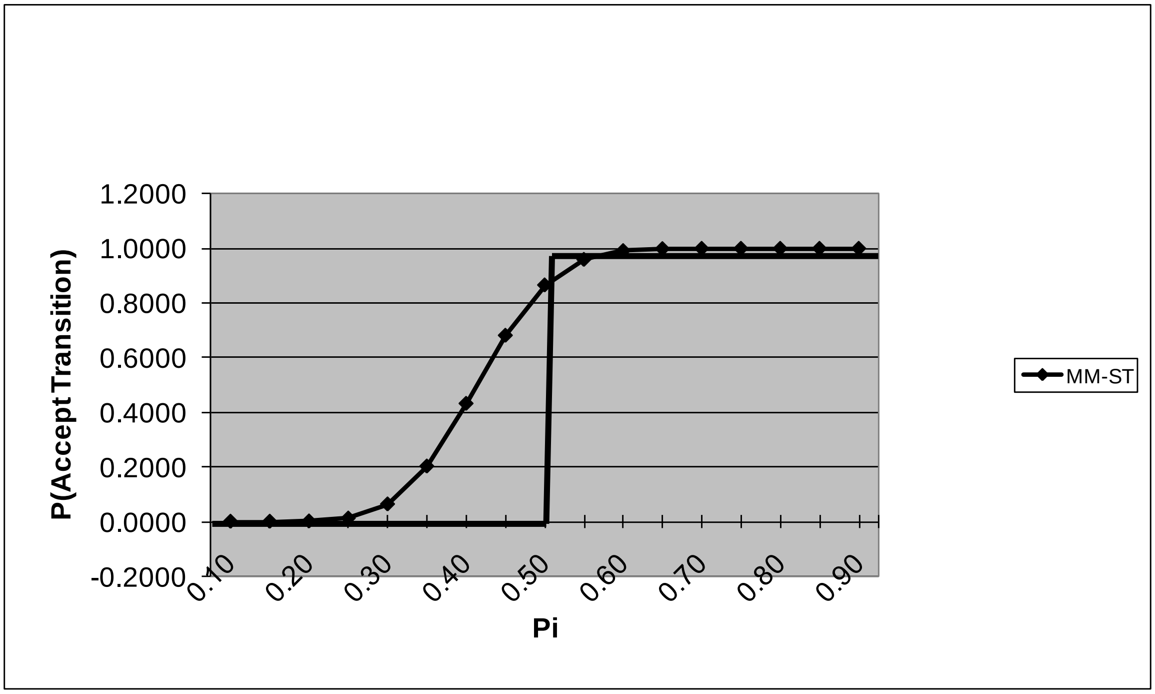


Figure C.17 MM-ST with Eight Respondents ($\alpha = 0.87$ and $\beta \leq 0.13$)

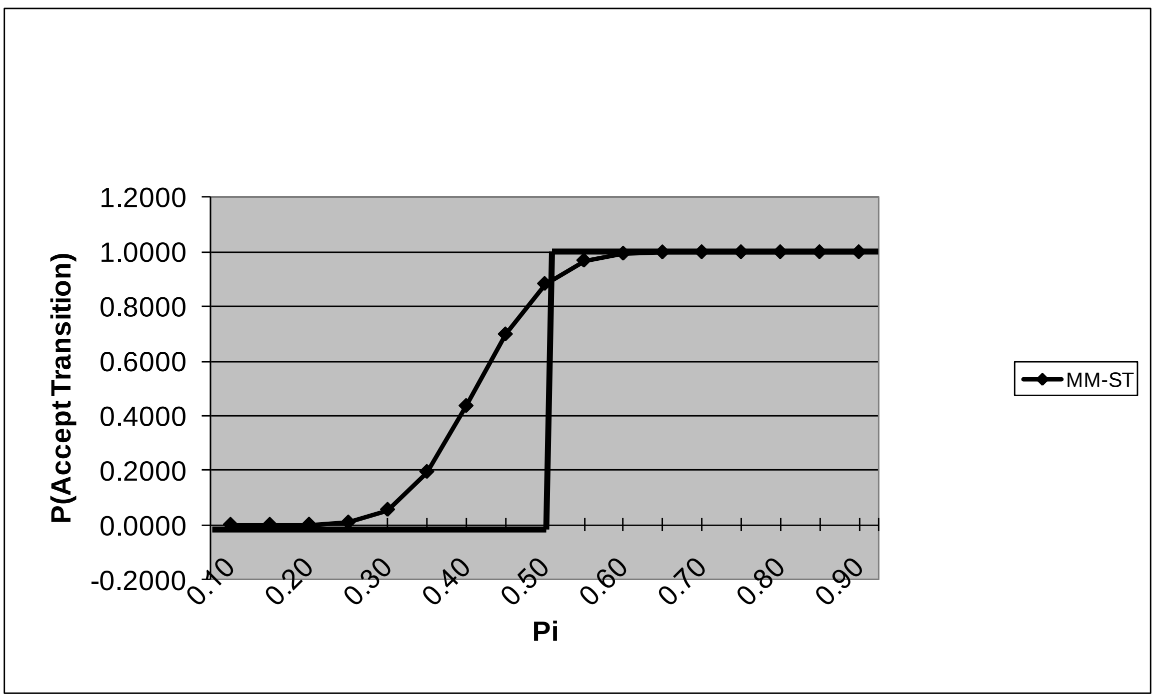


Figure C.18 MM-ST with Nine Respondents ($\alpha = 0.88$ and $\beta \leq 0.12$)

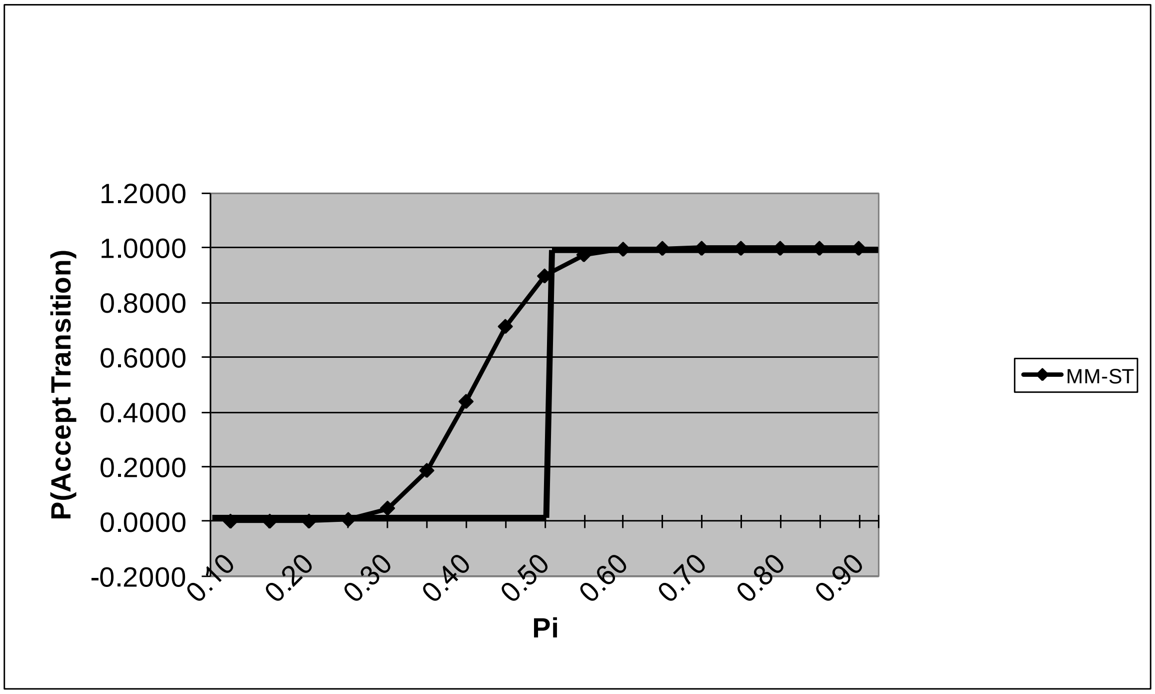


Figure C.19 MM-ST with Ten Respondents (α = 0.90 and β ≤ 0.10)

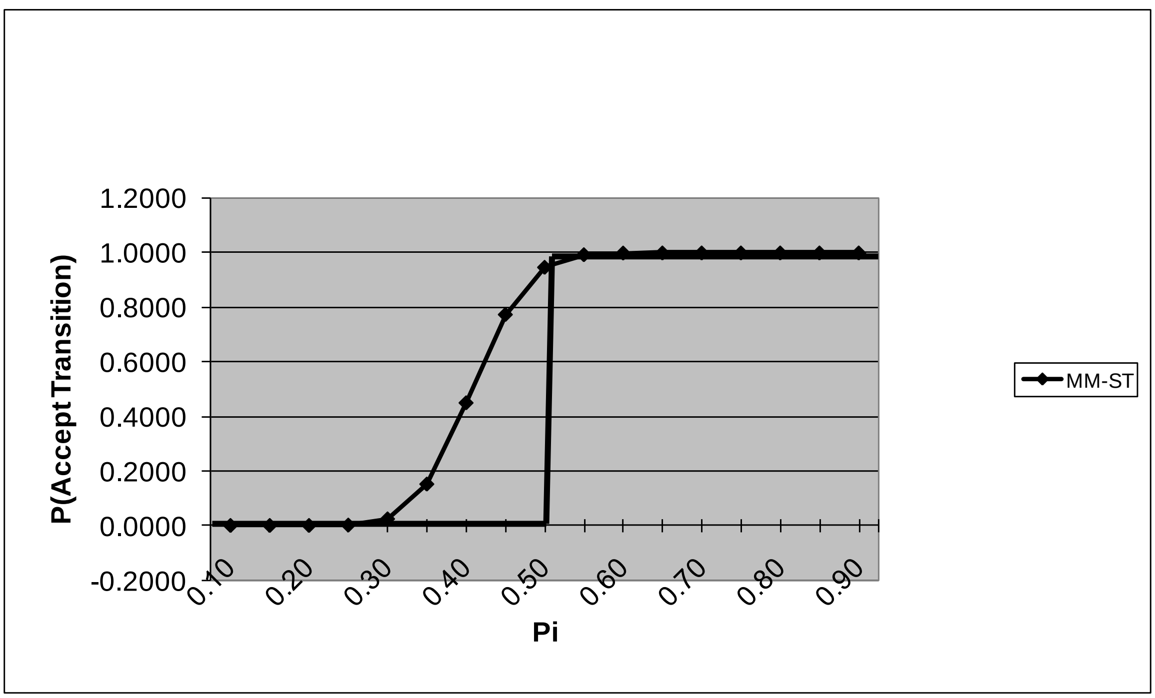


Figure C.20 MM-ST with Fifteen Respondents (α = 0.95 and β ≤ 0.05)

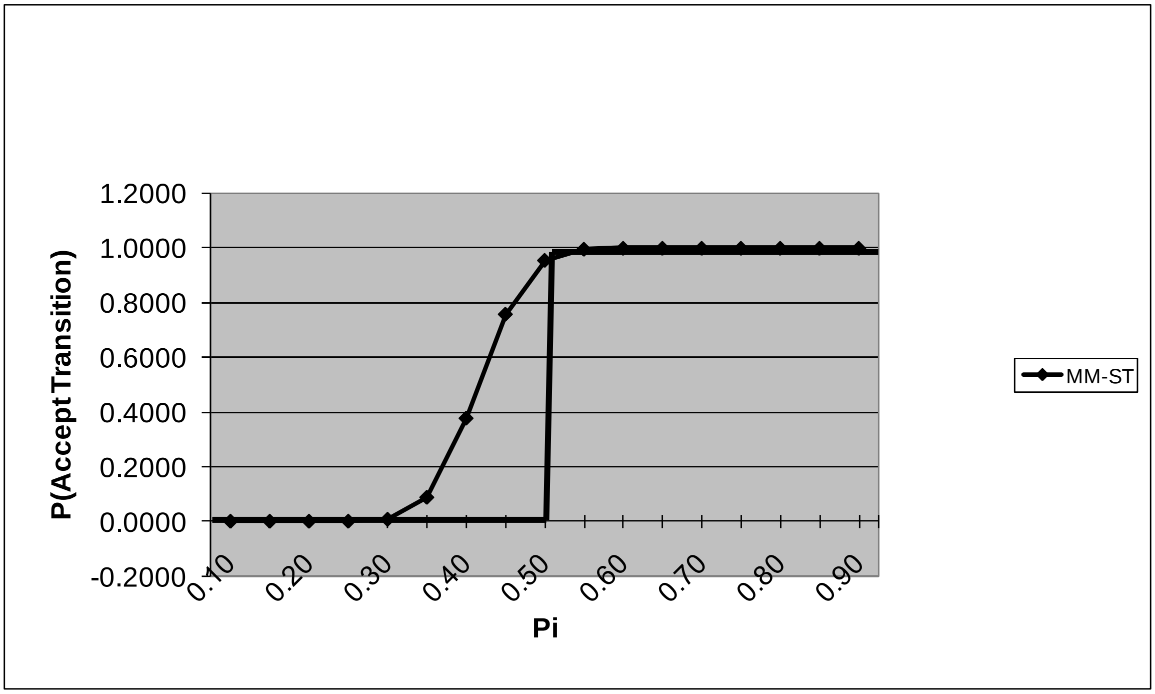


Figure C.21 MM-ST with Twenty Respondents (α = 0.96 and β ≤ 0.04)

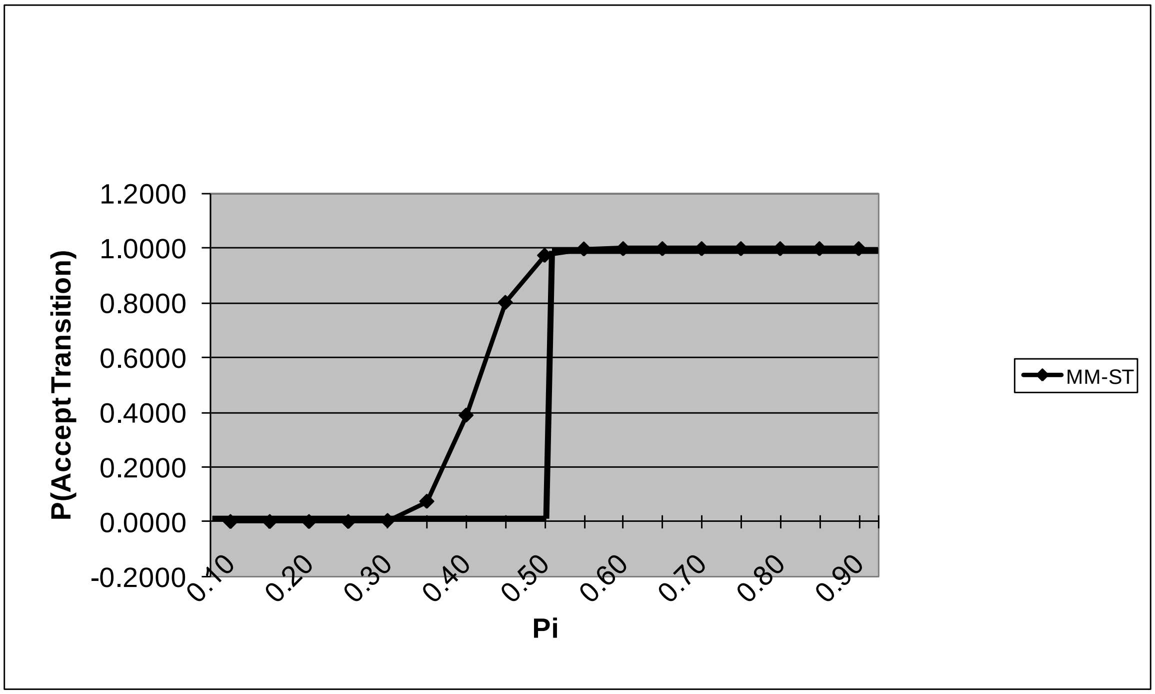


Figure C.22 MM-ST with Twenty-Five Respondents (α = 0.98 and β ≤ 0.02)

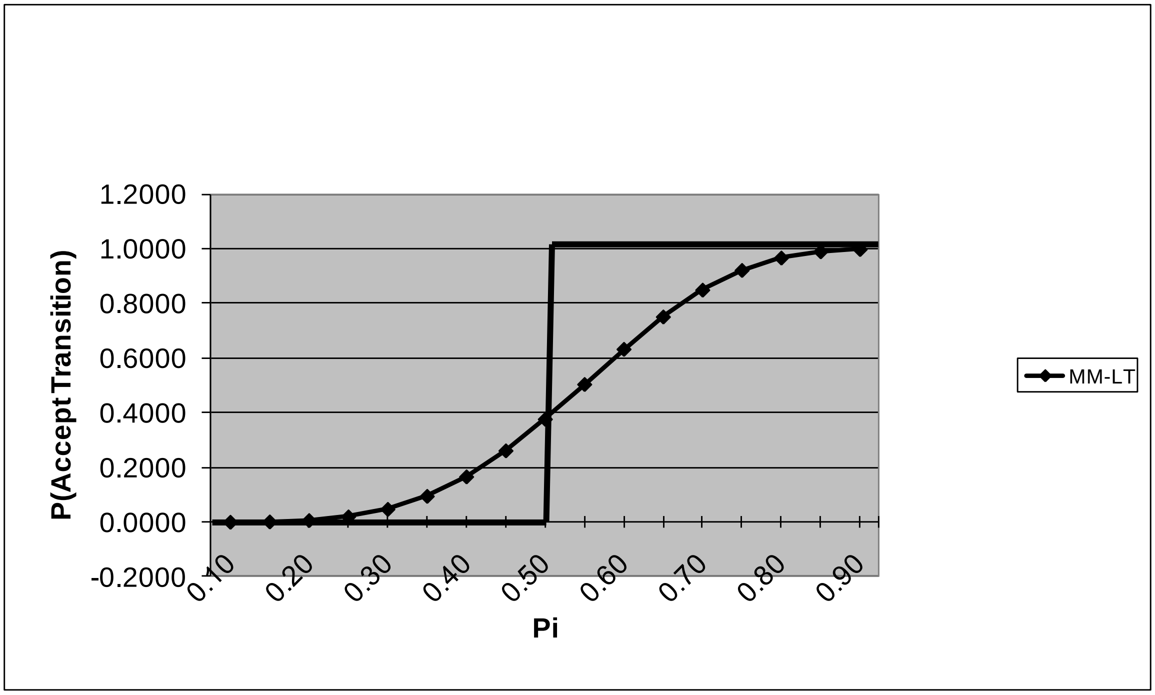


Figure C.23 MM-LT with Two Respondents (α = 0.38 and β ≤ 0.62)

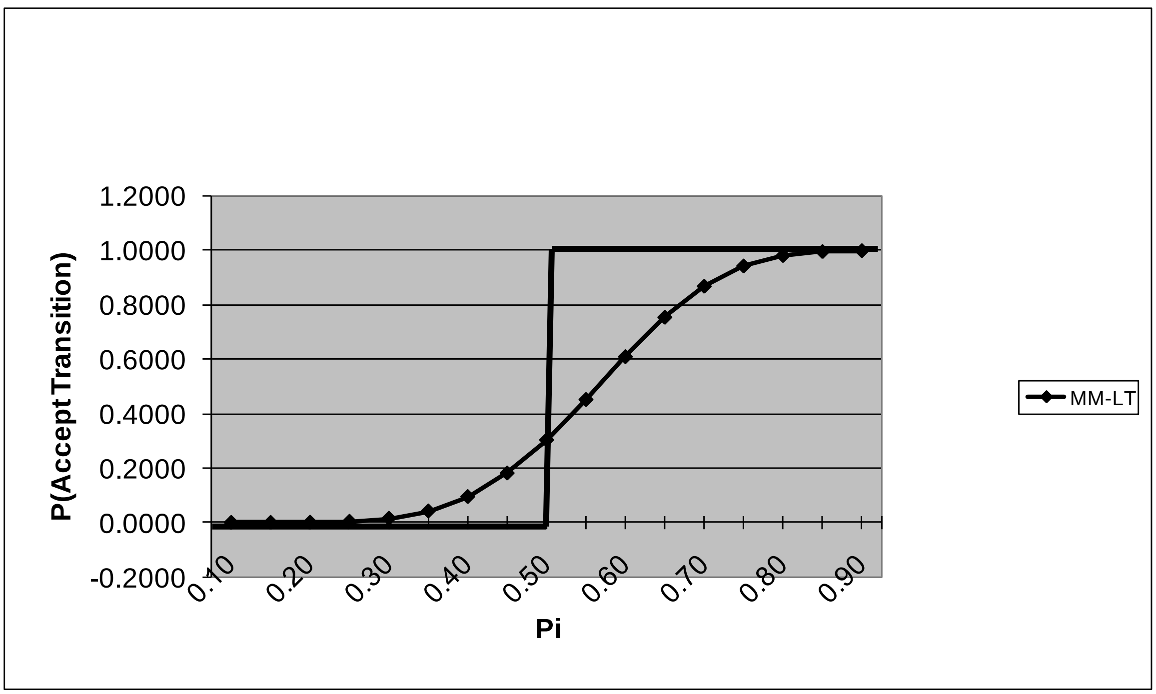


Figure C.24 MM-LT with Three Respondents (α = 0.30 and β ≤ 0.70)

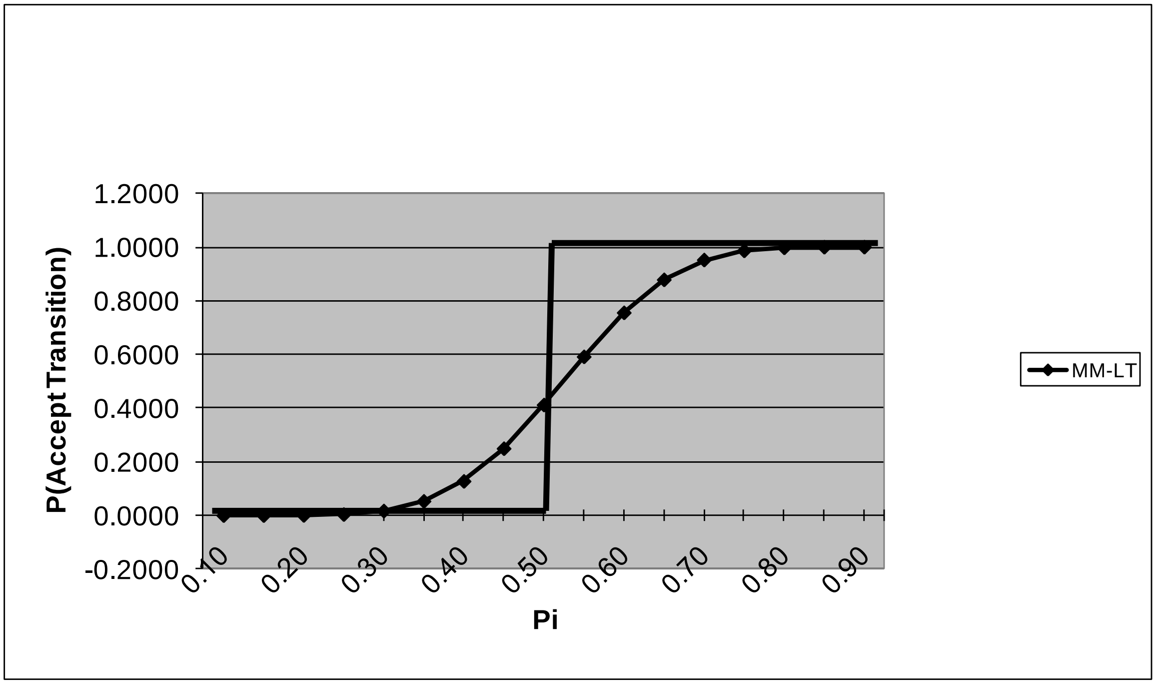


Figure C.25 MM-LT with Four Respondents (α = 0.41 and β ≤ 0.59)

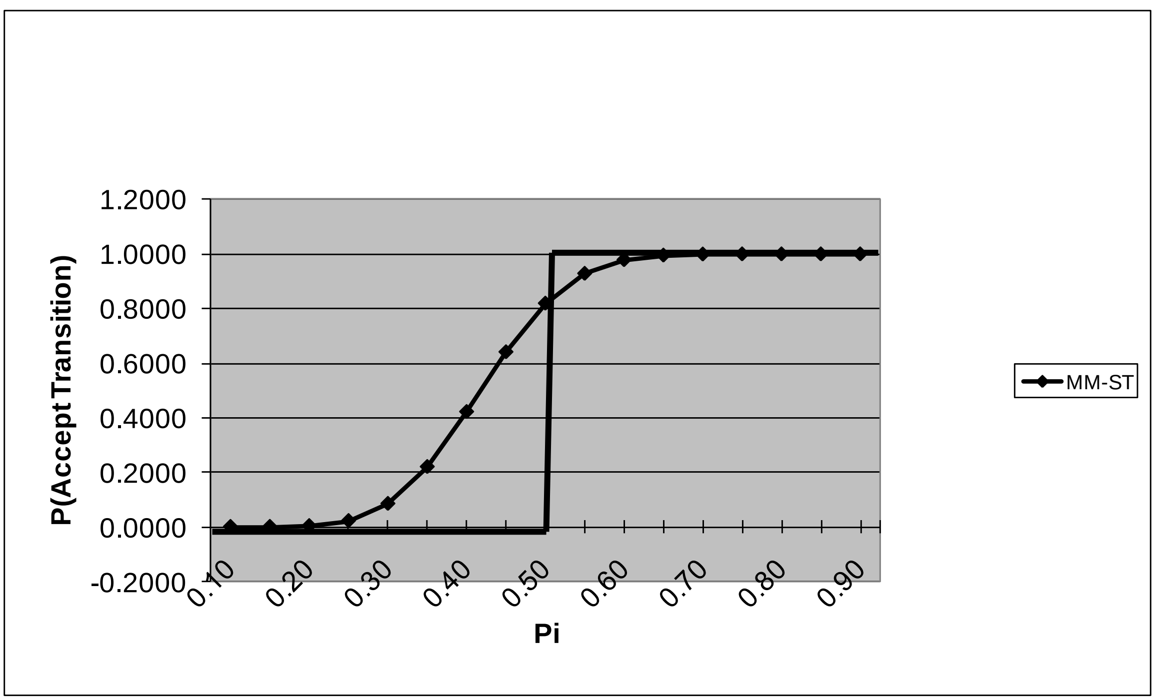


Figure C.26 MM-LT with Six Respondents (α = 0.29 and β ≤ 0.71)

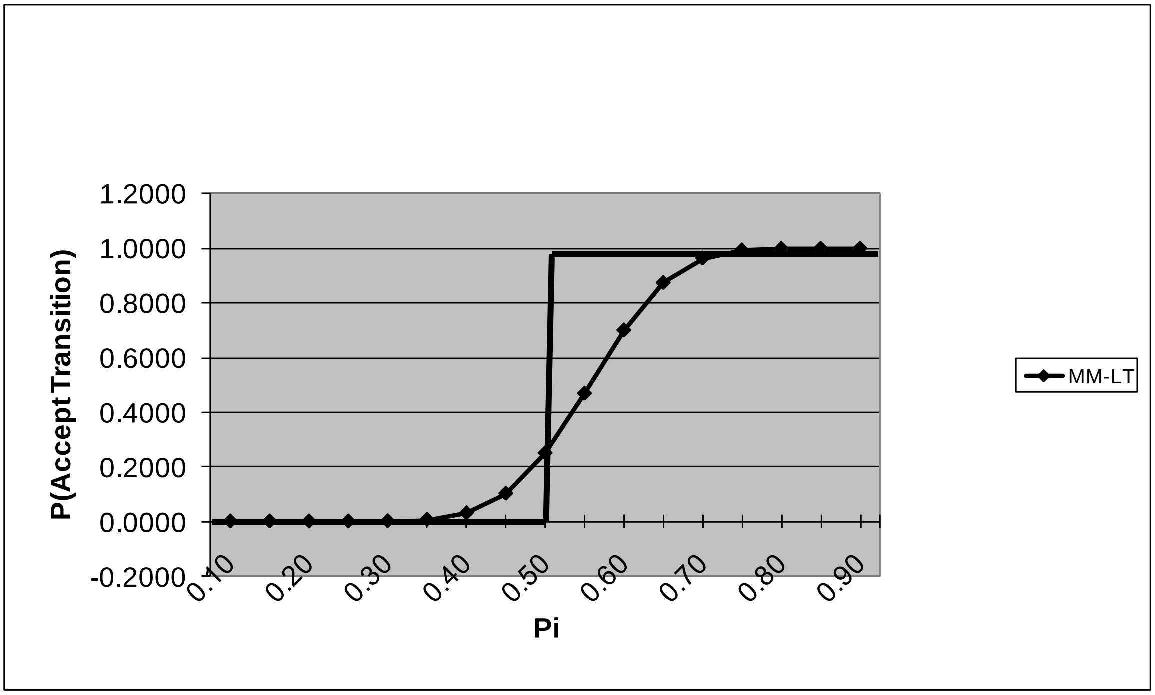


Figure C.27 MM-LT with Seven Respondents (α = 0.25 and β ≤ 0.75)

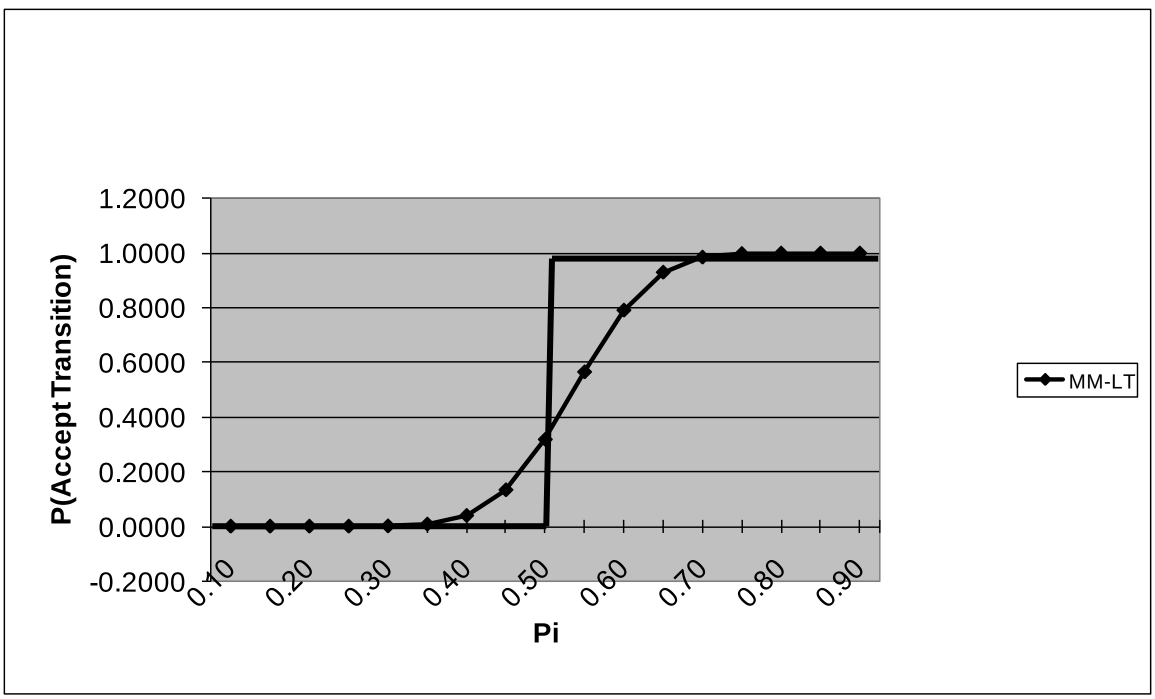


Figure C.28 MM-LT with Eight Respondents (α = 0.32 and β ≤ 0.68)

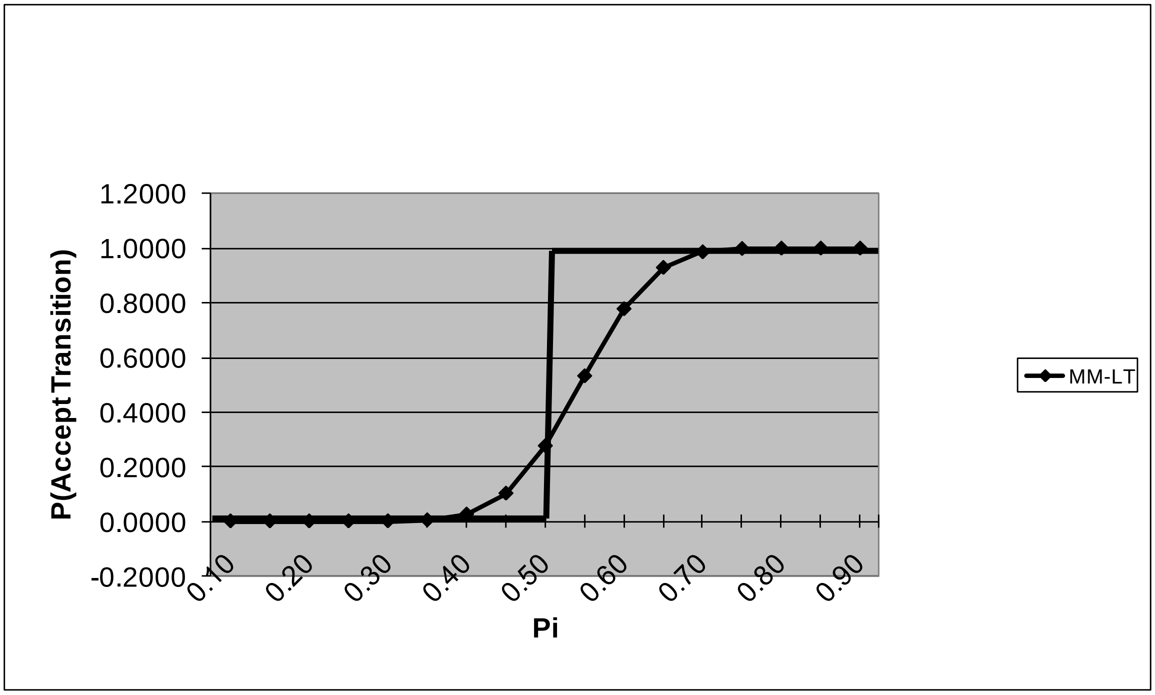


Figure C.29 MM-LT with Nine Respondents (α = 0.28 and β ≤ 0.72)

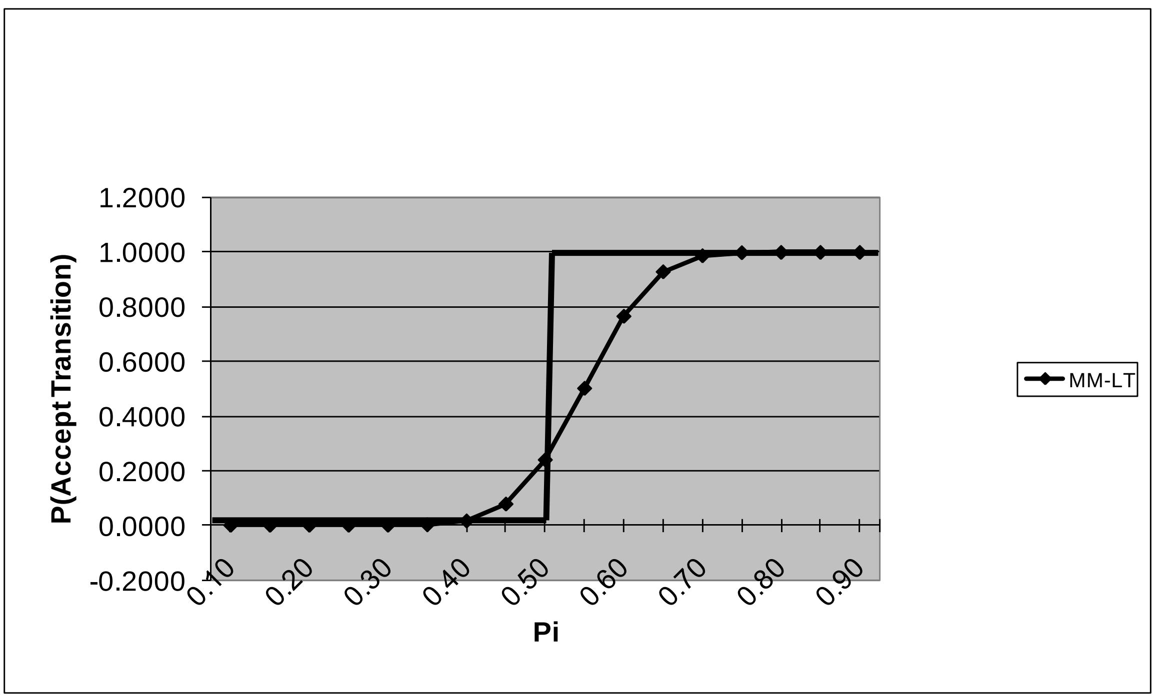


Figure C.30 MM-LT with Ten Respondents (α = 0.24 and β ≤ 0.76)

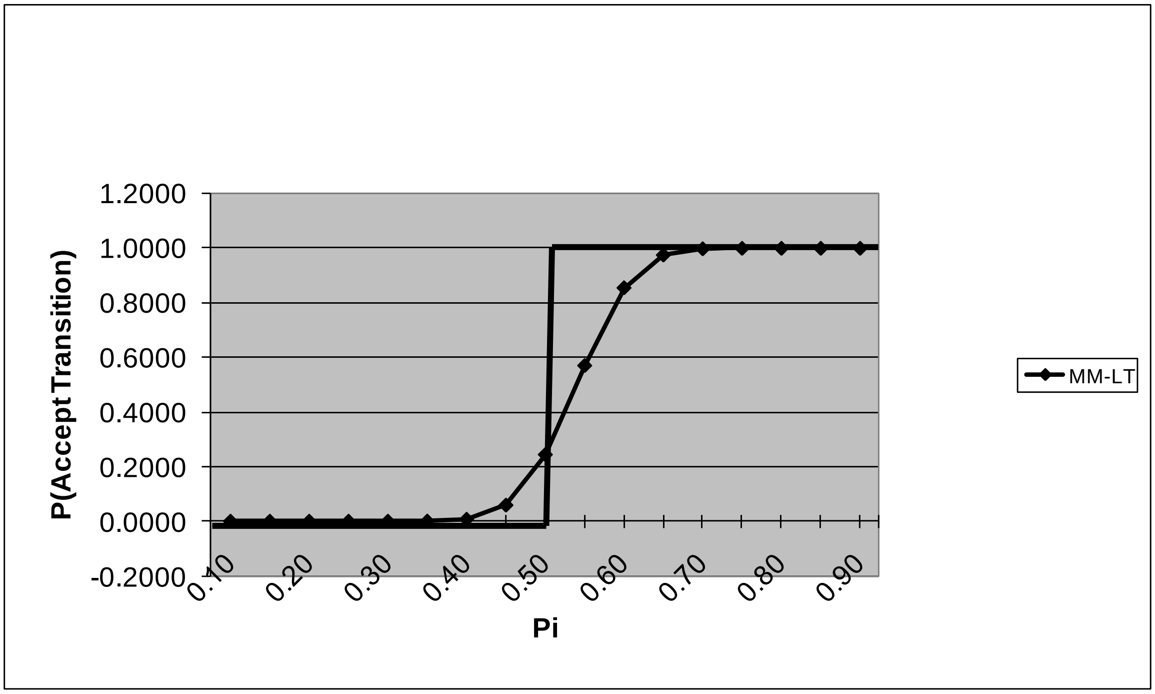


Figure C.31 MM-LT with Fifteen Respondents ($\alpha = 0.24$ and $\beta \leq 0.76$)

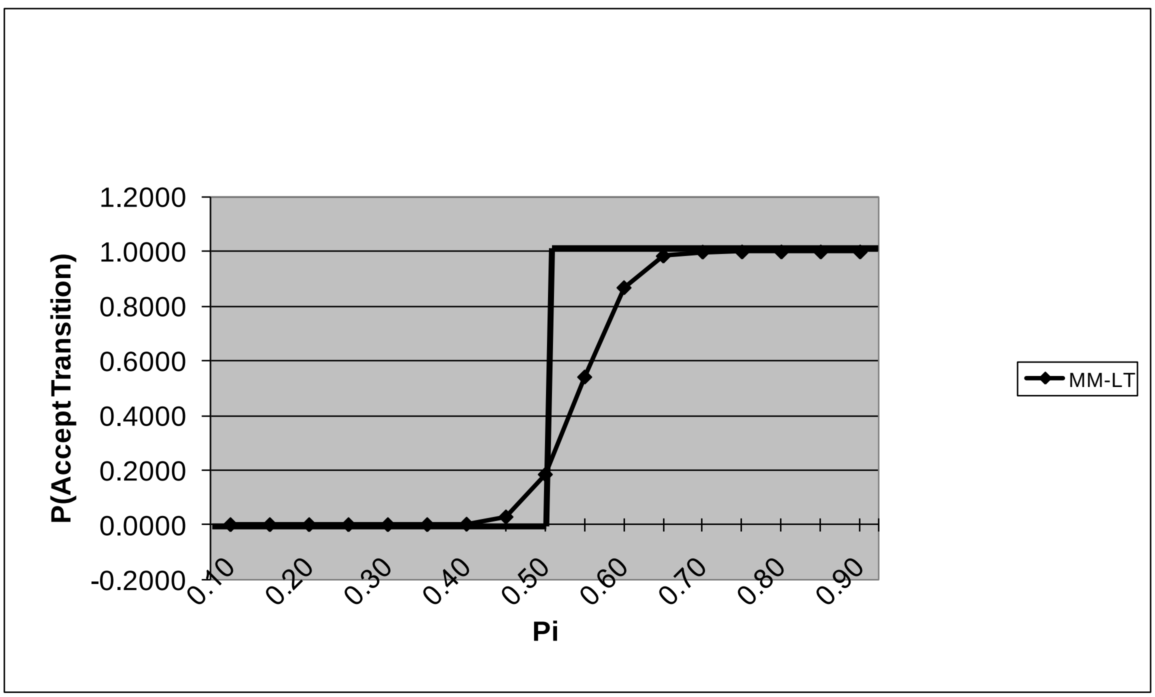


Figure C.32 MM-LT with Twenty Respondents ($\alpha = 0.18$ and $\beta \leq 0.82$)

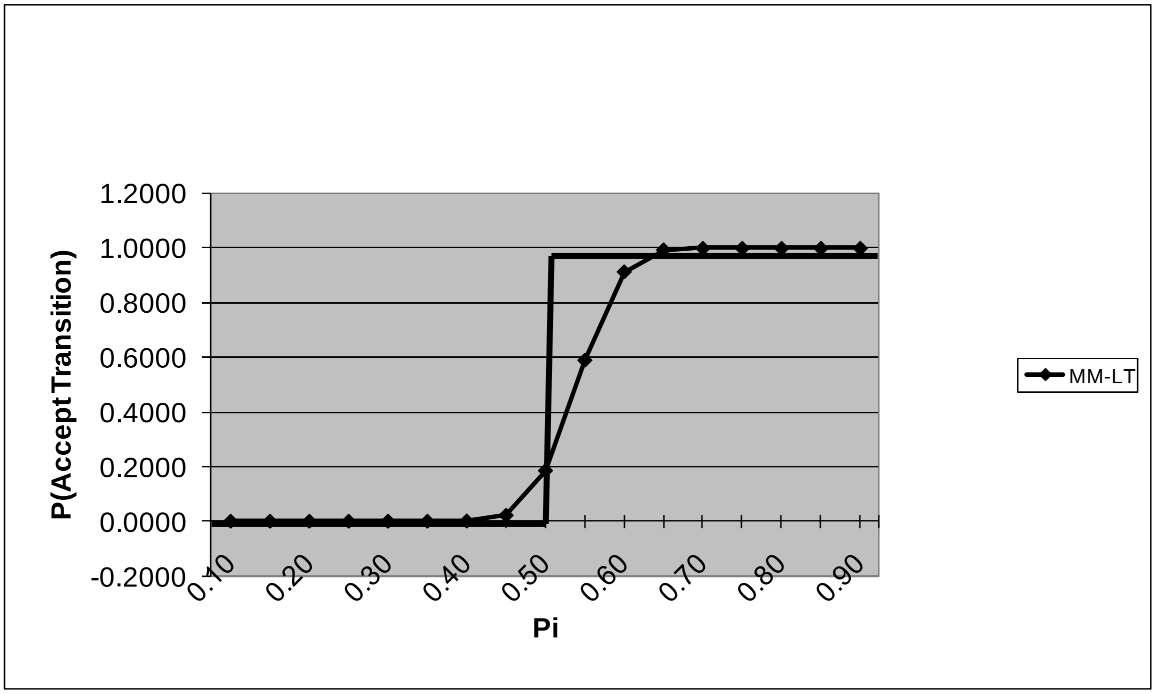


Figure C.33 MM-LT with Twenty-Five Respondents ($\alpha = 0.19$ and $\beta \leq 0.81$)

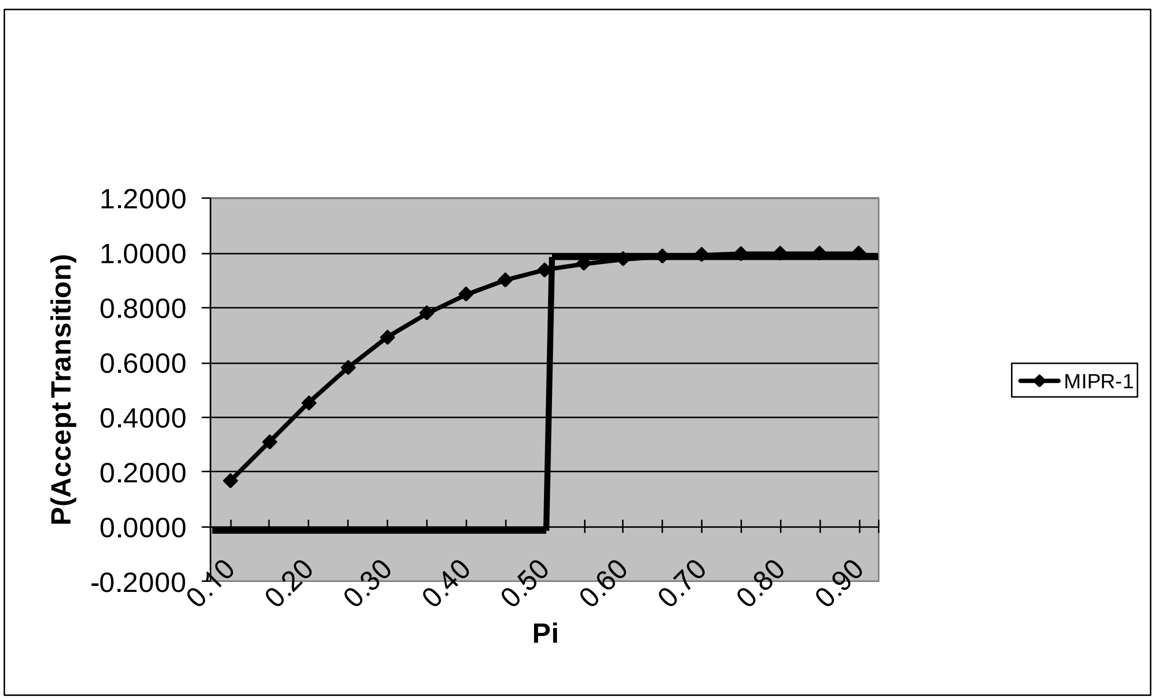


Figure C.34 MIPR-1 with Two Respondents ($\alpha = 0.94$ and $\beta \leq 0.06$)

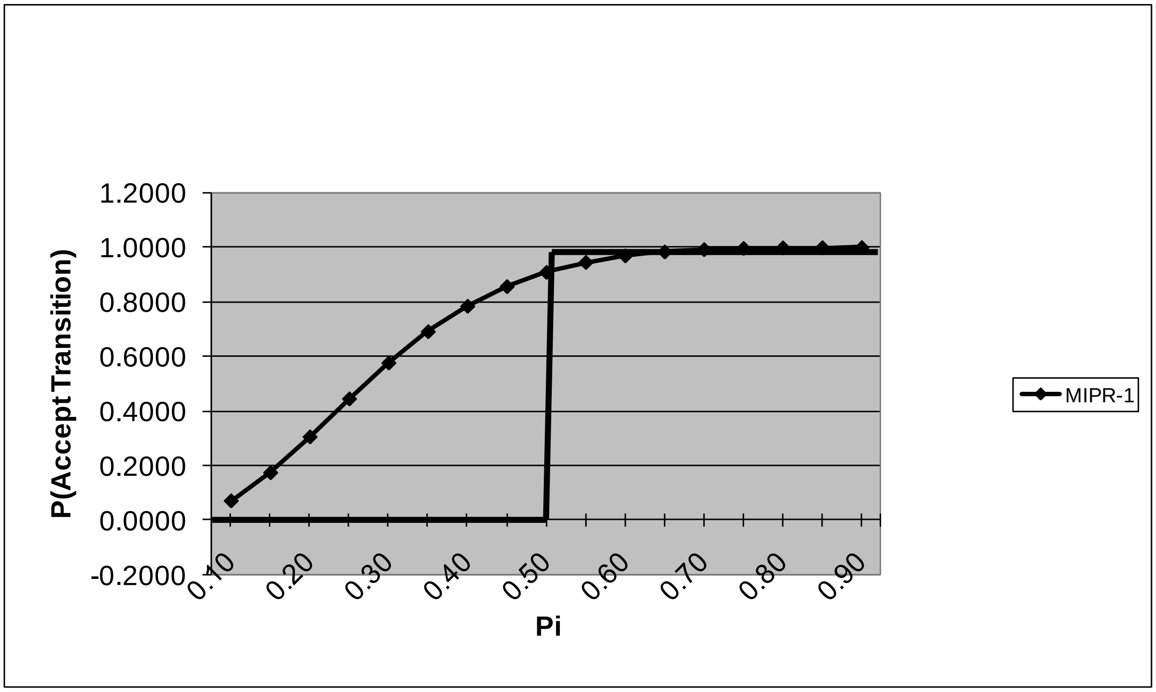


Figure C.35 MIPR-1 with Three Respondents (α = 0.91 and β ≤ 0.09)

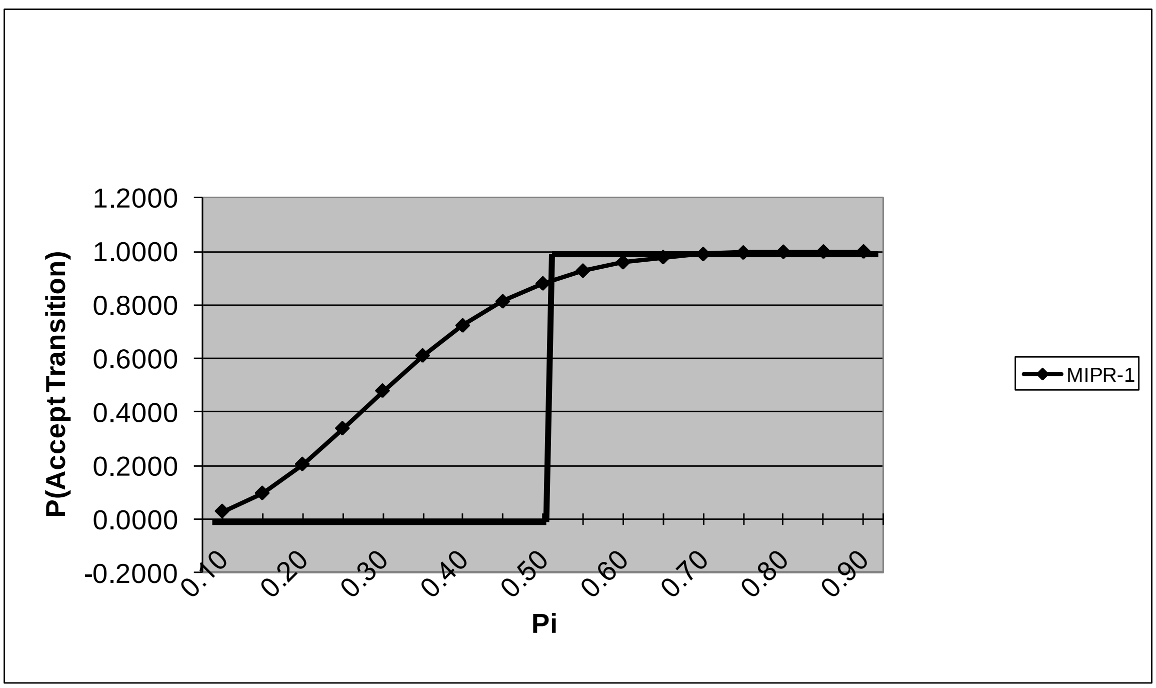


Figure C.36 MIPR-1 with Four Respondents (α = 0.88 and β ≤ 0.12)

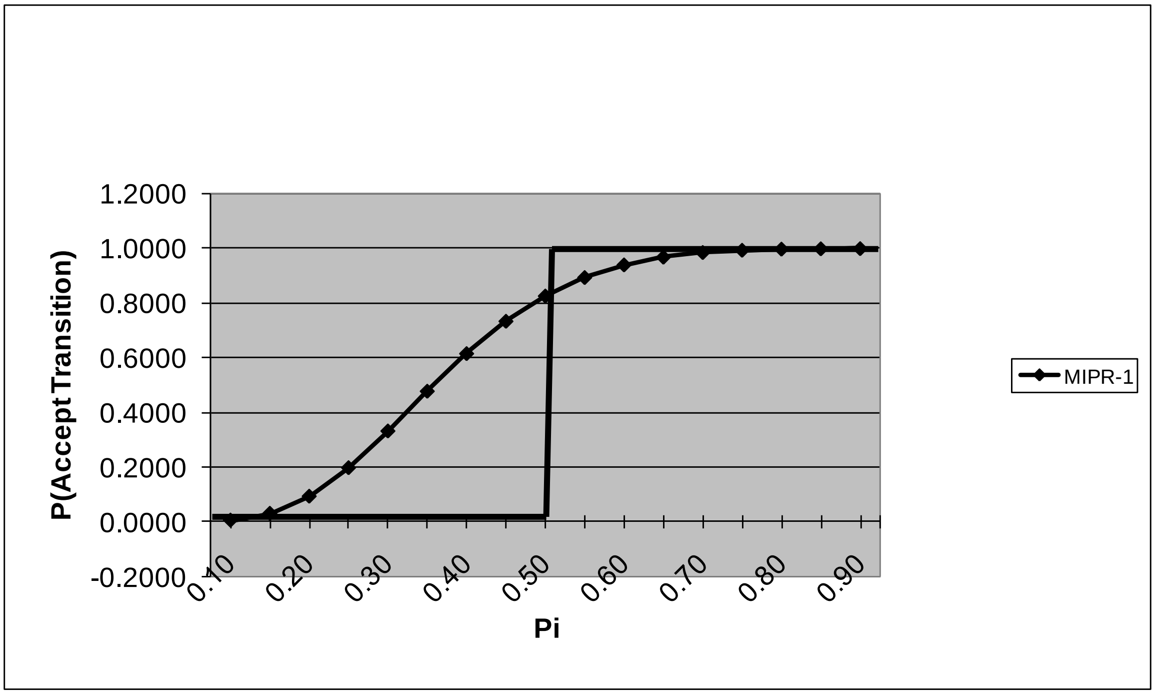


Figure C.37 MIPR-1 with Six Respondents (α = 0.83 and β ≤ 0.17)

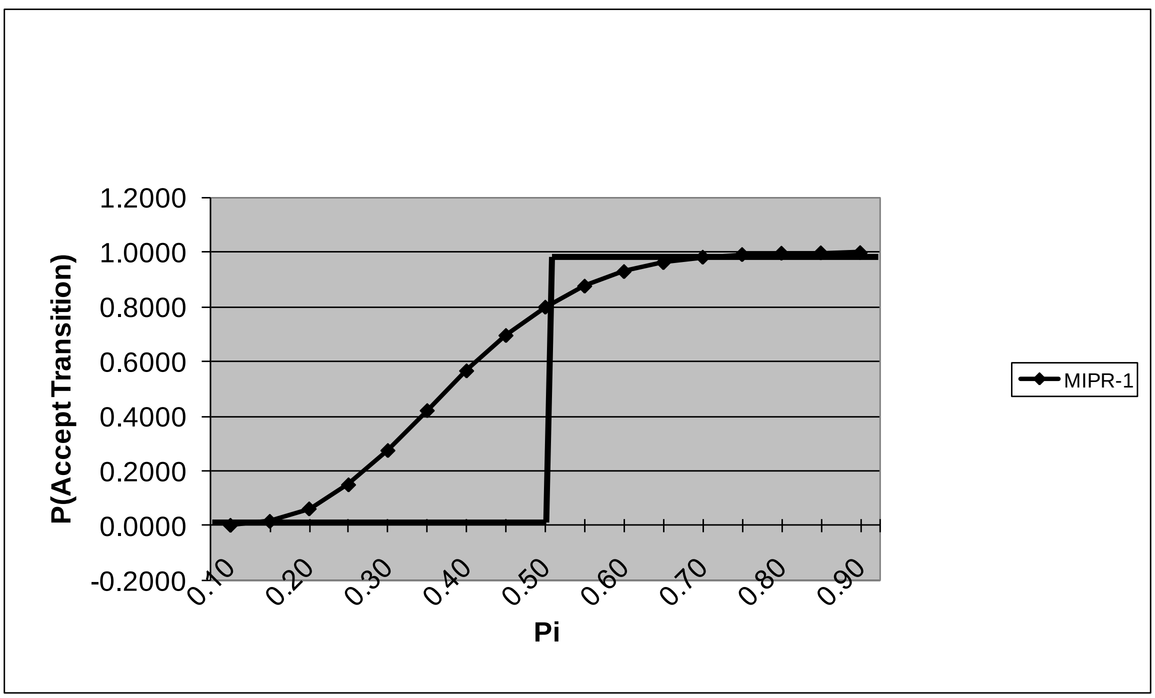


Figure C.38 MIPR-1 with Seven Respondents (α = 0.80 and β ≤ 0.20)

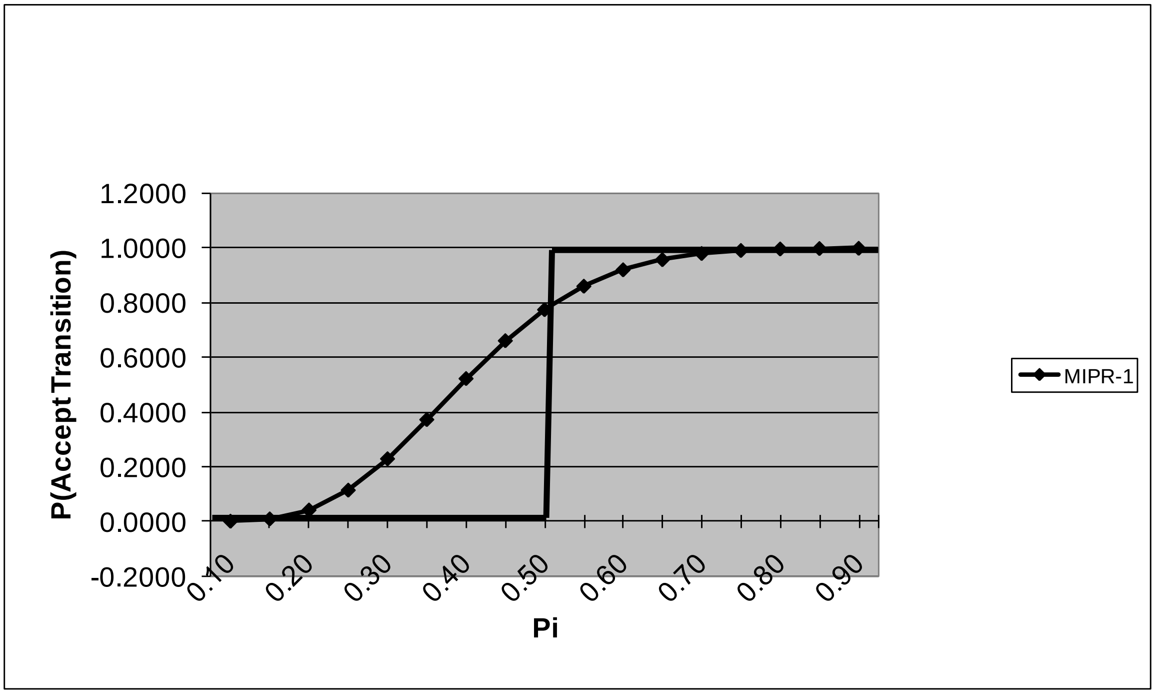


Figure C.39 MIPR-1 with Eight Respondents (α = 0.78 and β ≤ 0.22)

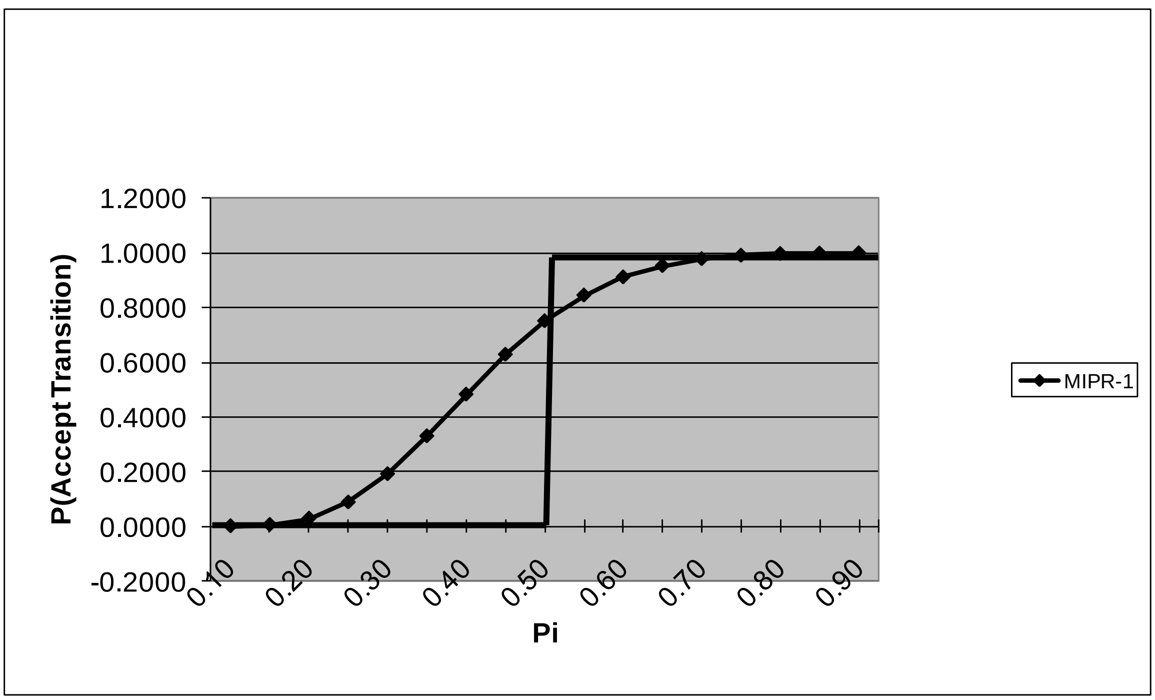


Figure C.40 MIPR-1 with Nine Respondents (α = 0.75 and β ≤ 0.25)

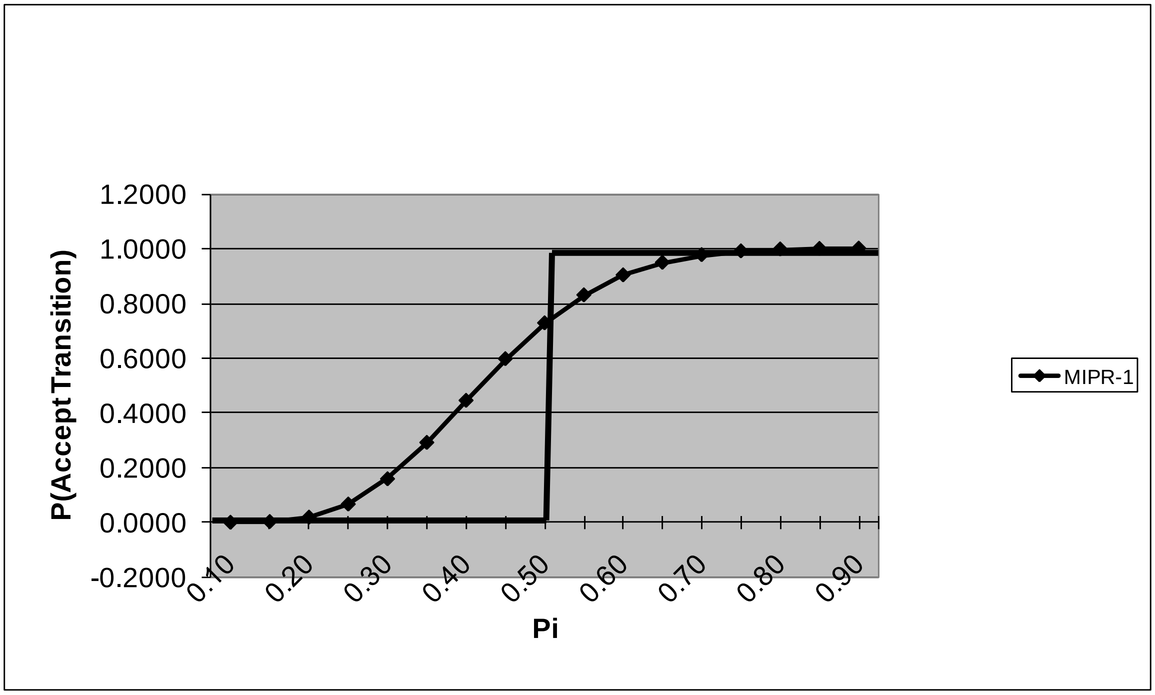


Figure C.41 MIPR-1 with Ten Respondents (α = 0.73 and β ≤ 0.27)

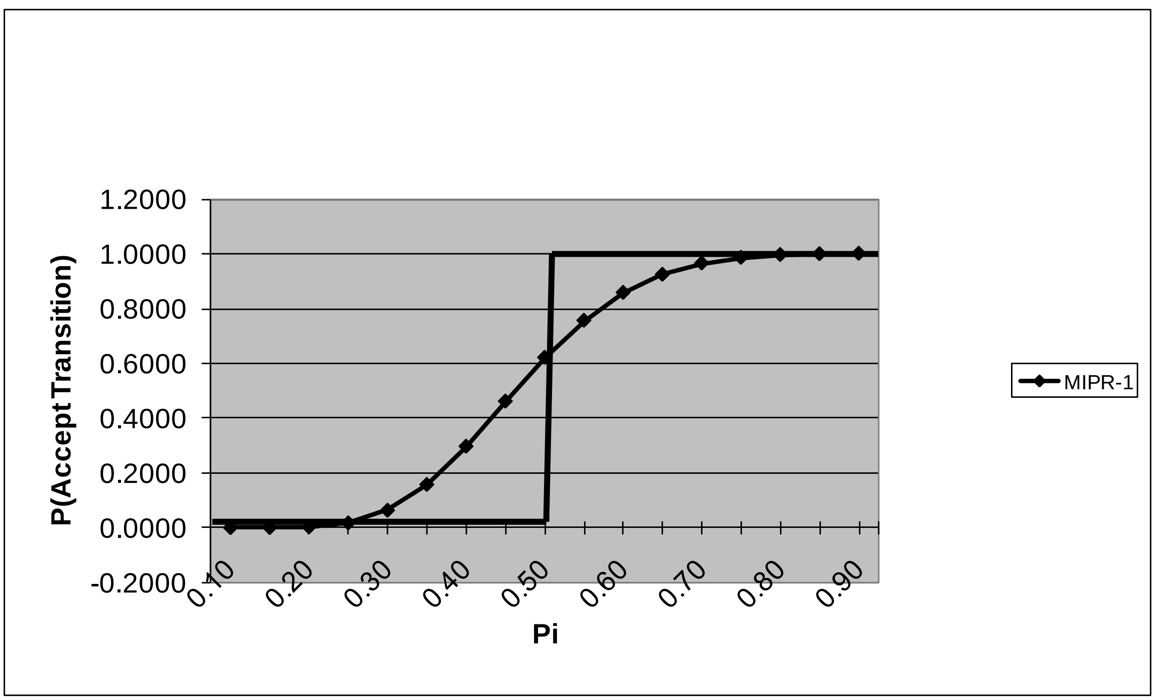


Figure C.42 MIPR-1 with Fifteen Respondents (α = 0.62 and β ≤ 0.38)

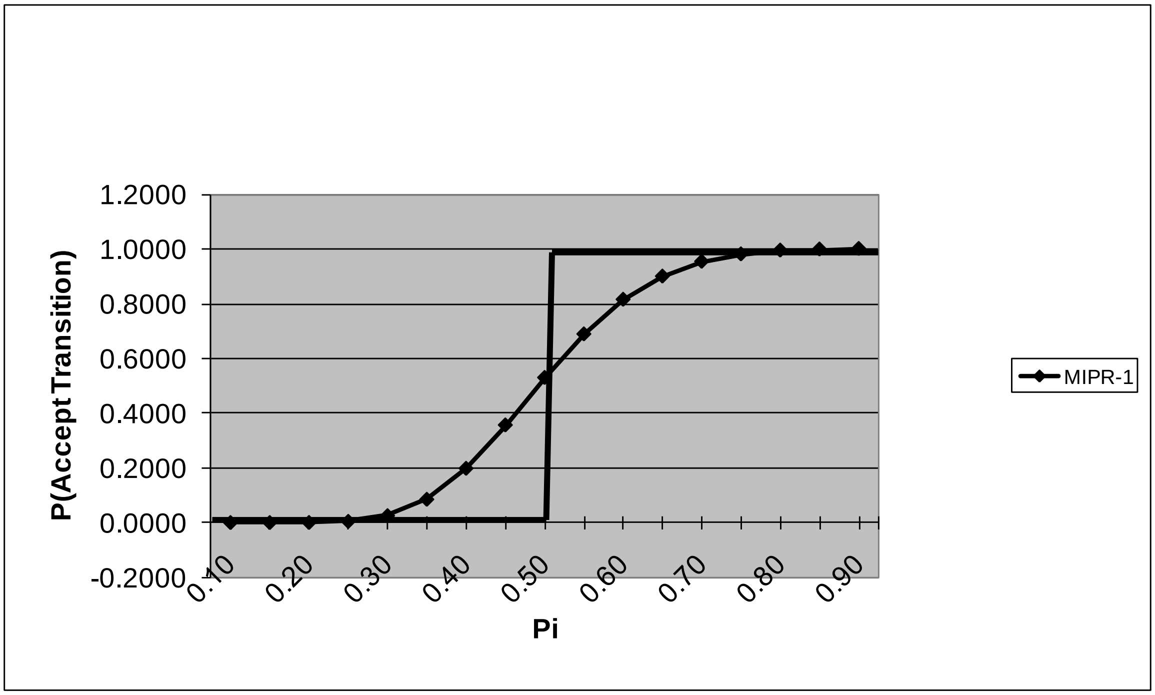


Figure C.43 MIPR-1 with Twenty Respondents (α = 0.53 and β ≤ 0.47)

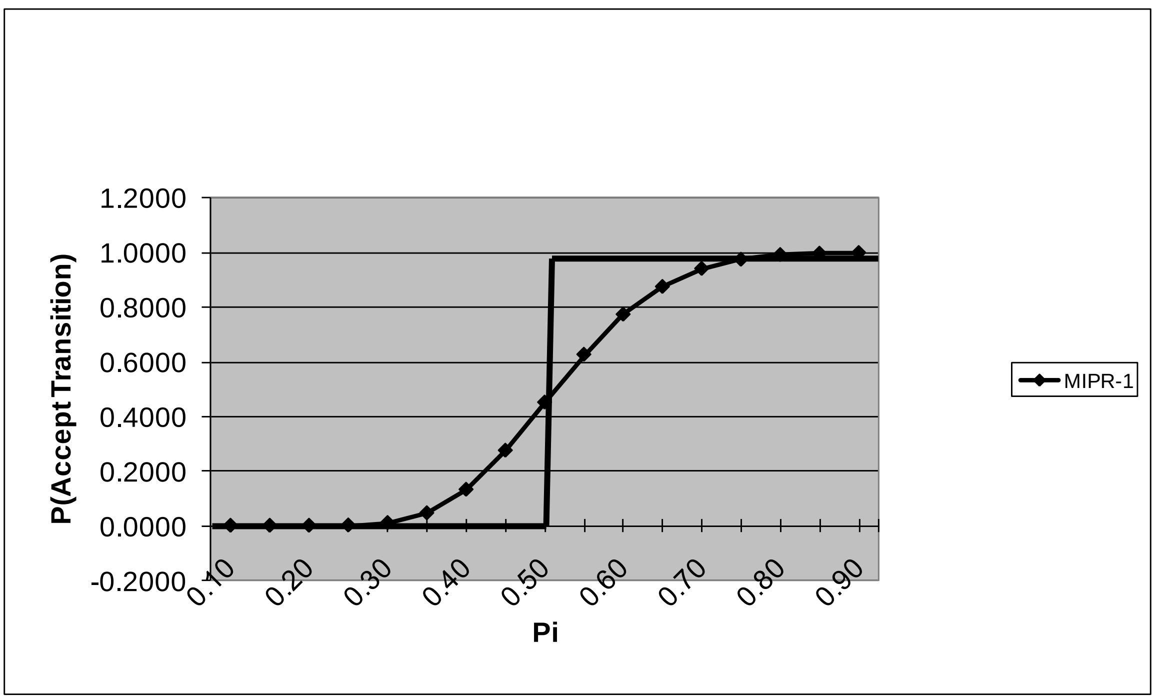


Figure C.44 MIPR-1 with Twenty-Five Respondents (α = 0.45 and β ≤ 0.55)

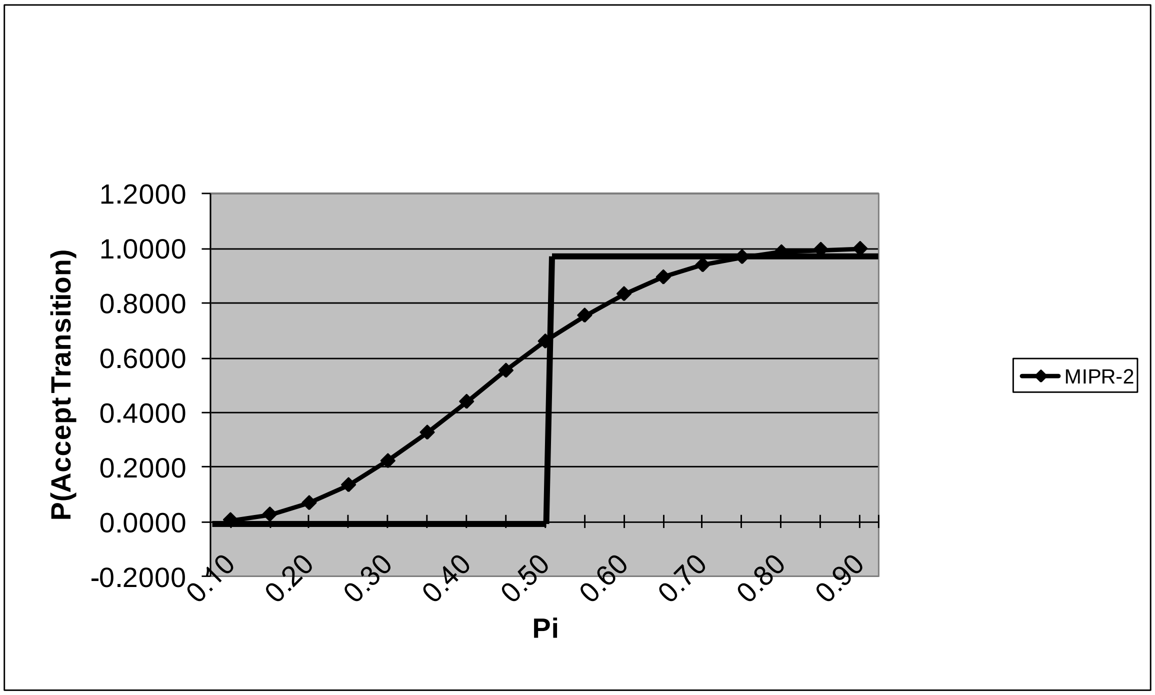


Figure C.45 MIPR-2 with Two Respondents ($\alpha = 0.66$ and $\beta \leq 0.34$)

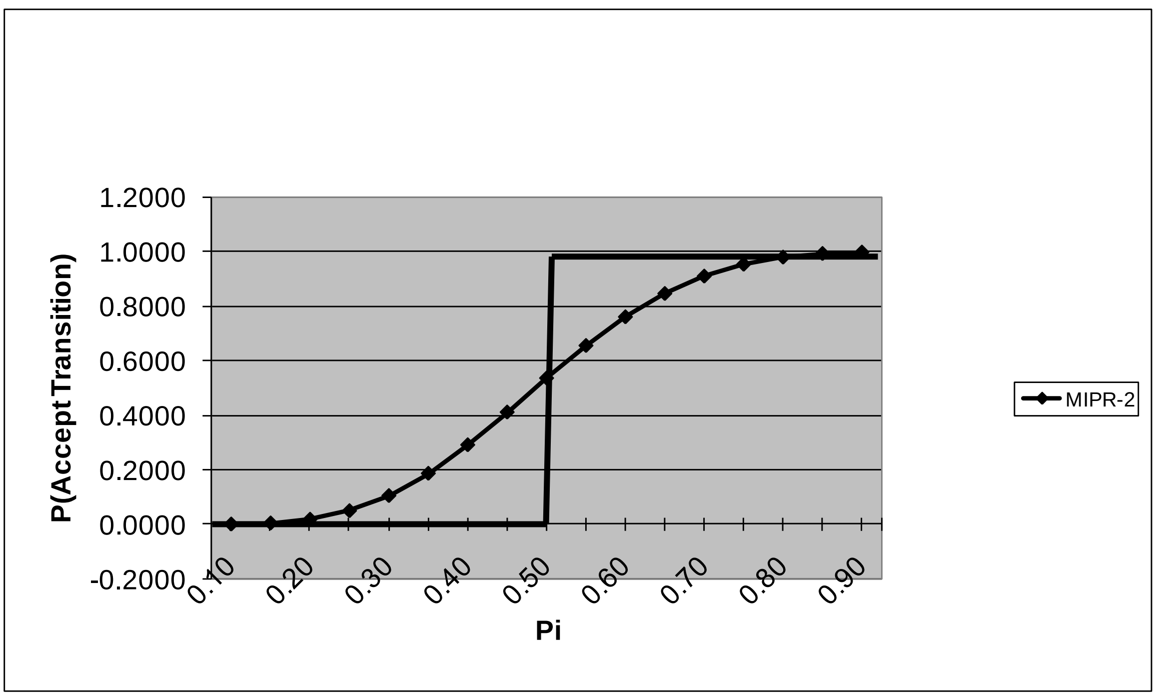


Figure C.46 MIPR-2 with Three Respondents ($\alpha = 0.54$ and $\beta \leq 0.46$)

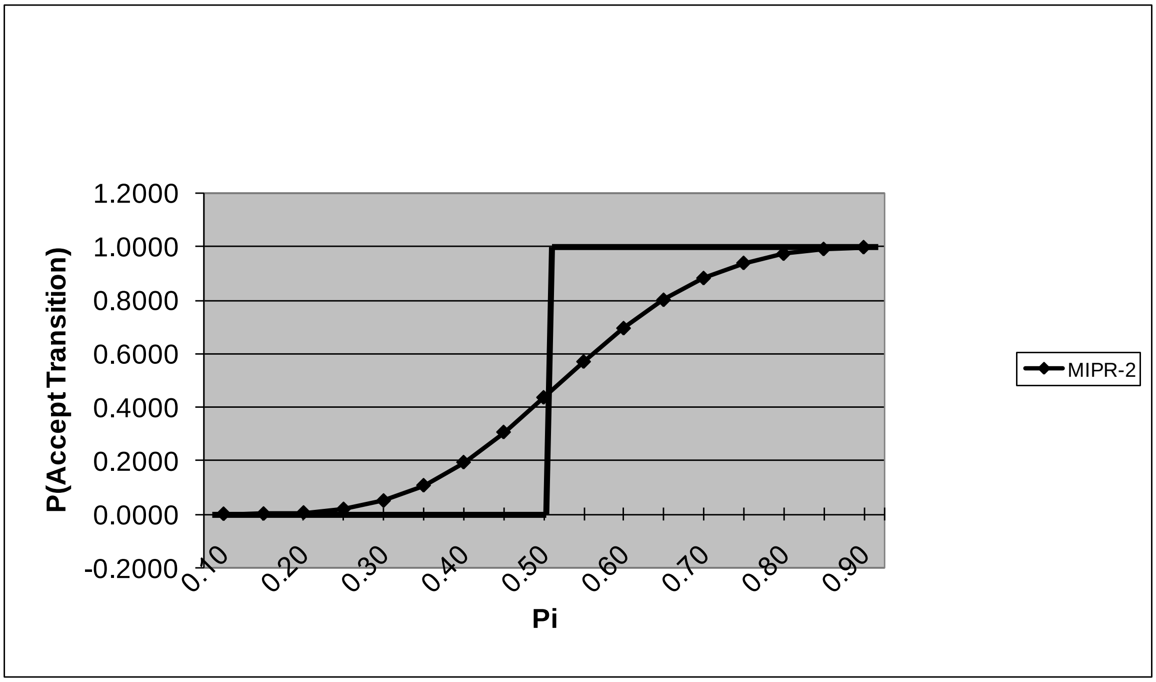


Figure C.47 MIPR-2 with Four Respondents ($\alpha = 0.44$ and $\beta \leq 0.56$)

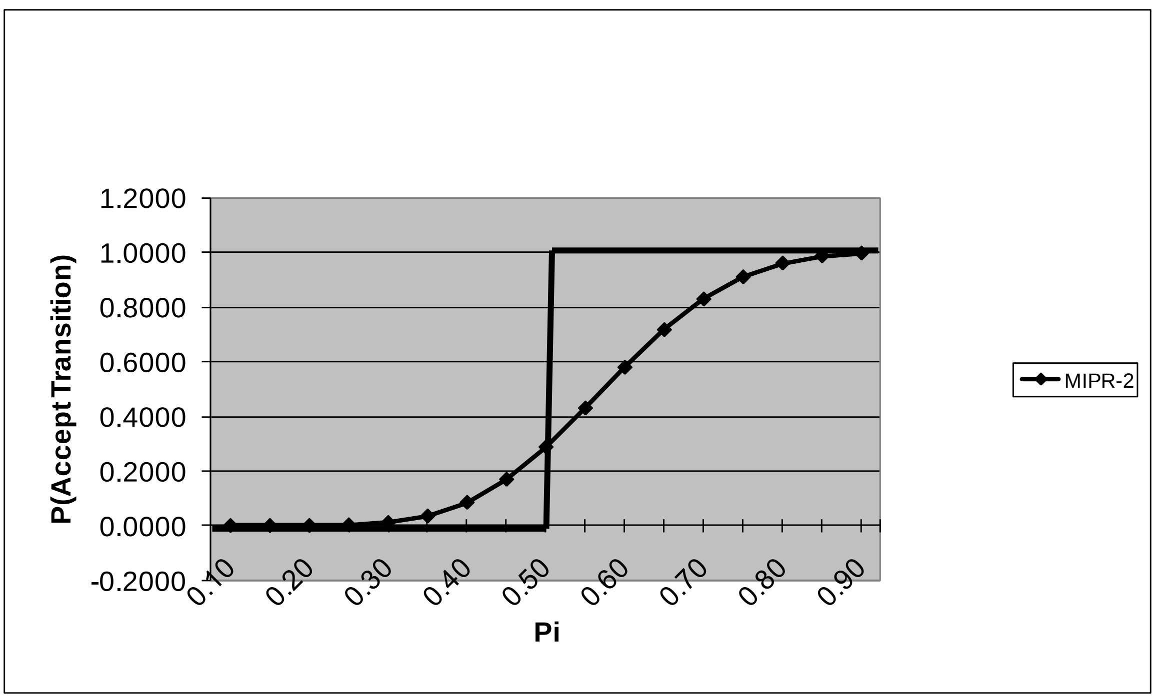


Figure C.48 MIPR-2 with Six Respondents ($\alpha = 0.29$ and $\beta \leq 0.71$)

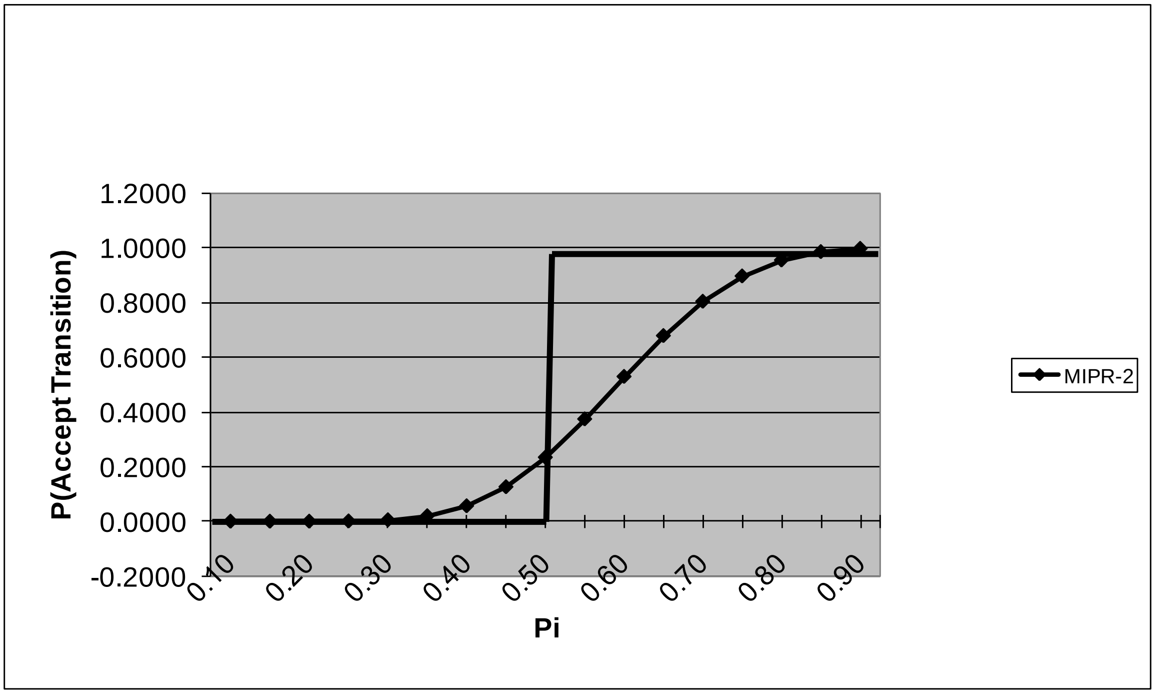


Figure C.49 MIPR-2 with Seven Respondents ($\alpha = 0.23$ and $\beta \leq 0.77$)

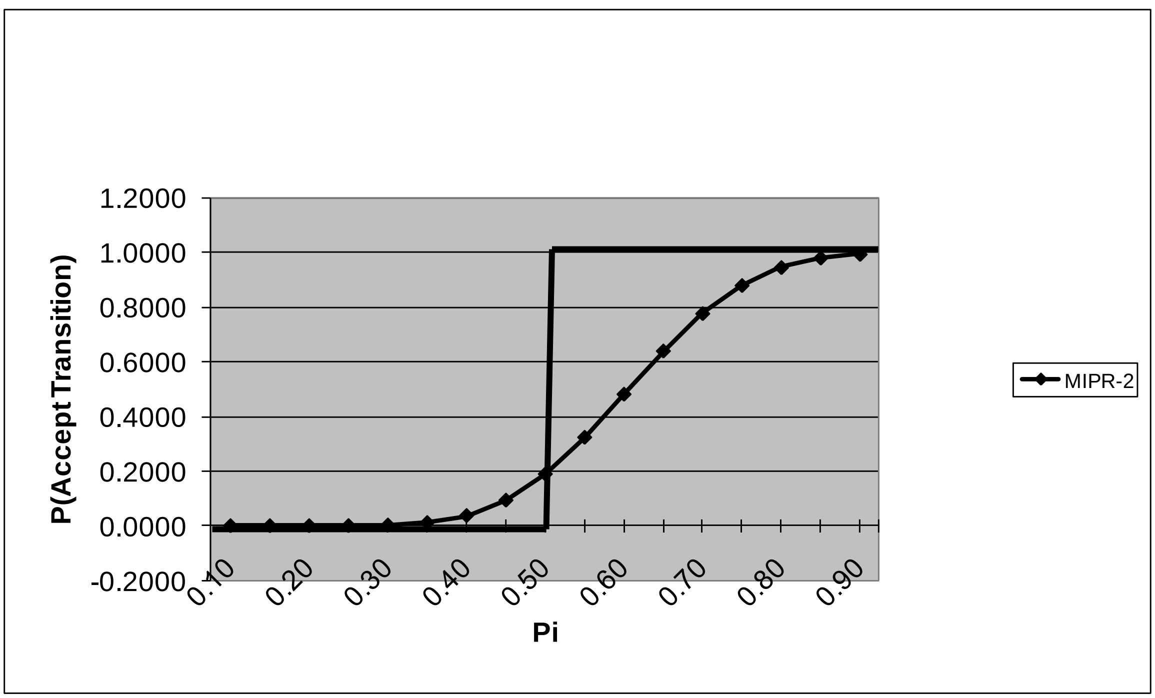


Figure C.50 MIPR-2 with Eight Respondents ($\alpha = 0.19$ and $\beta \leq 0.81$)

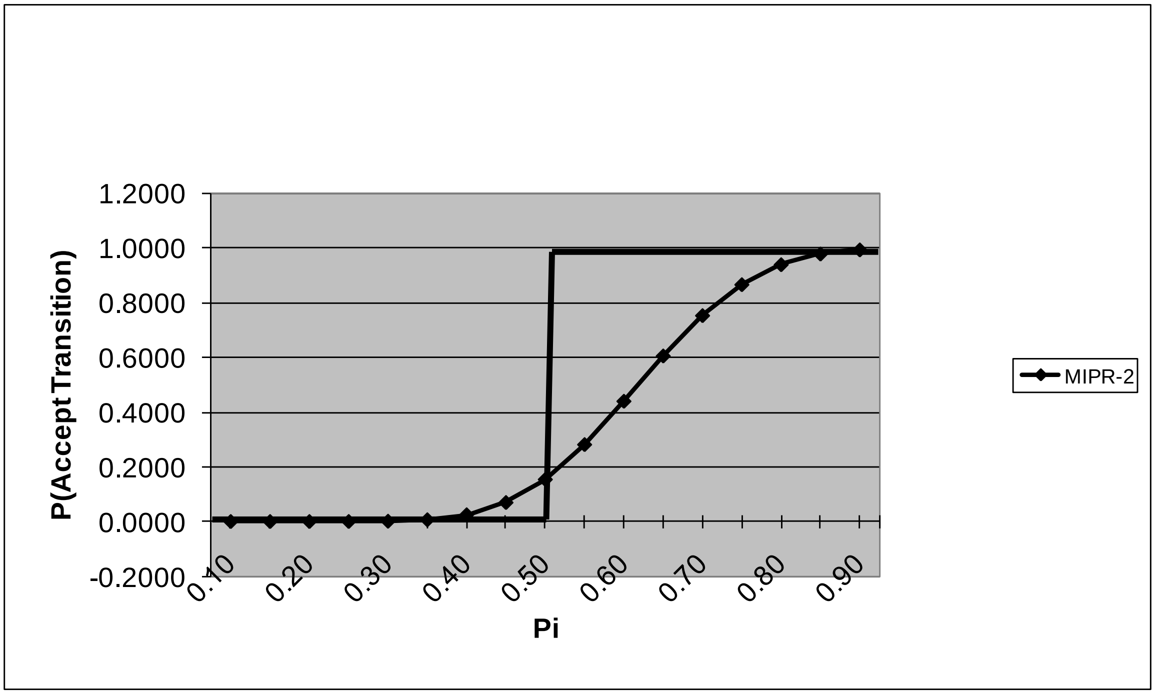


Figure C.51 MIPR-2 with Nine Respondents ($\alpha = 0.15$ and $\beta \leq 0.85$)

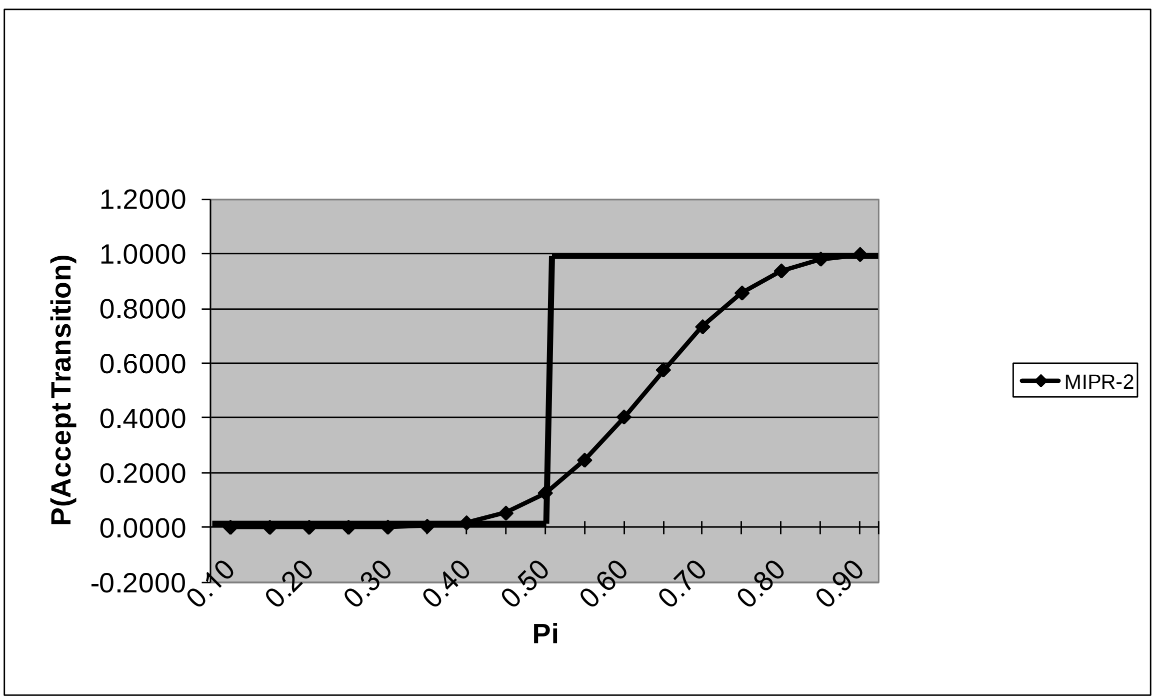


Figure C.52 MIPR-2 with Ten Respondents ($\alpha = 0.13$ and $\beta \leq 0.87$)

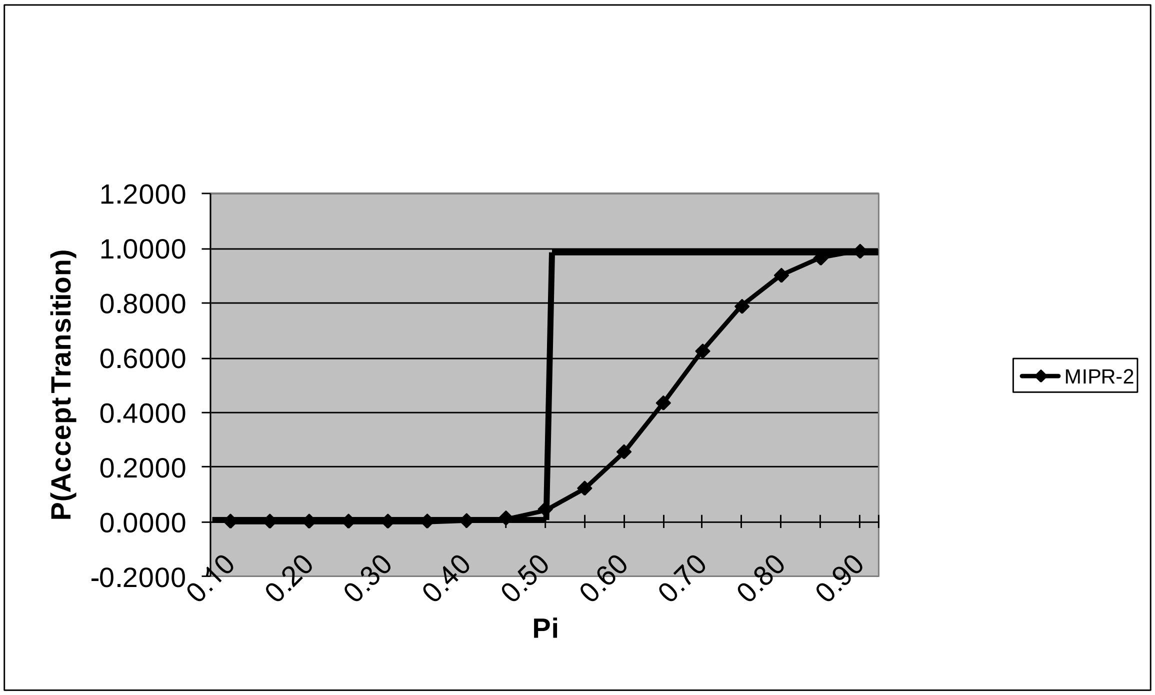


Figure C.53 MIPR-2 with Fifteen Respondents ($\alpha = 0.04$ and $\beta \leq 0.96$)

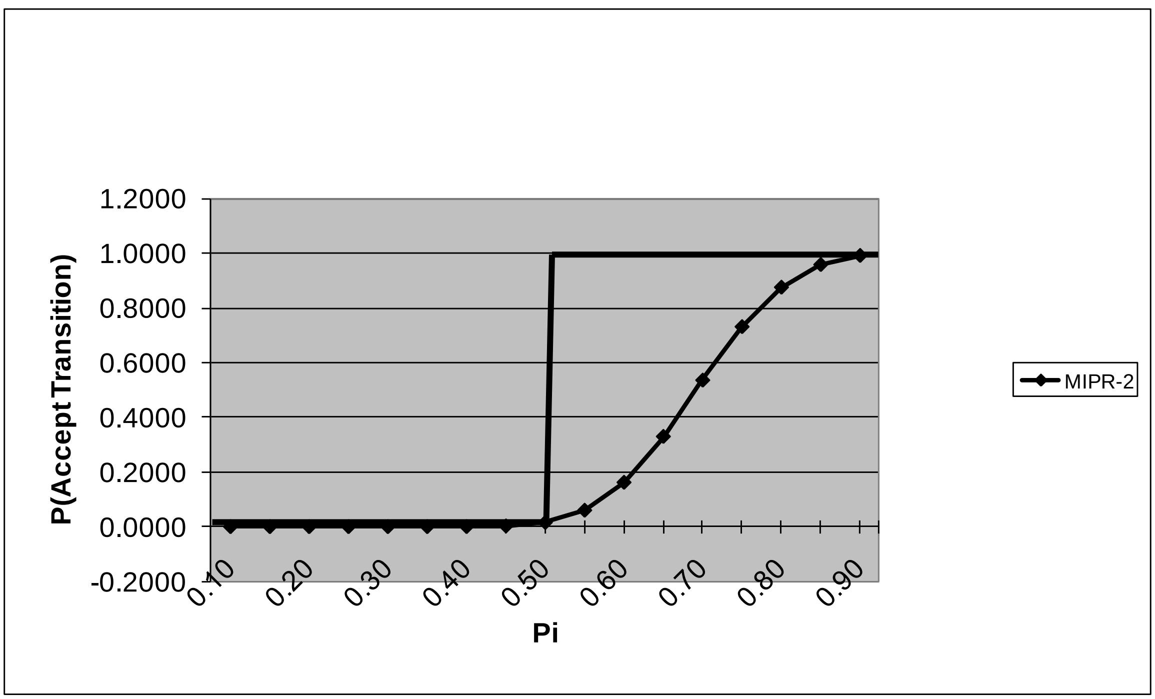


Figure C.54 MIPR-2 with Twenty Respondents ($\alpha = 0.02$ and $\beta \leq 0.98$)

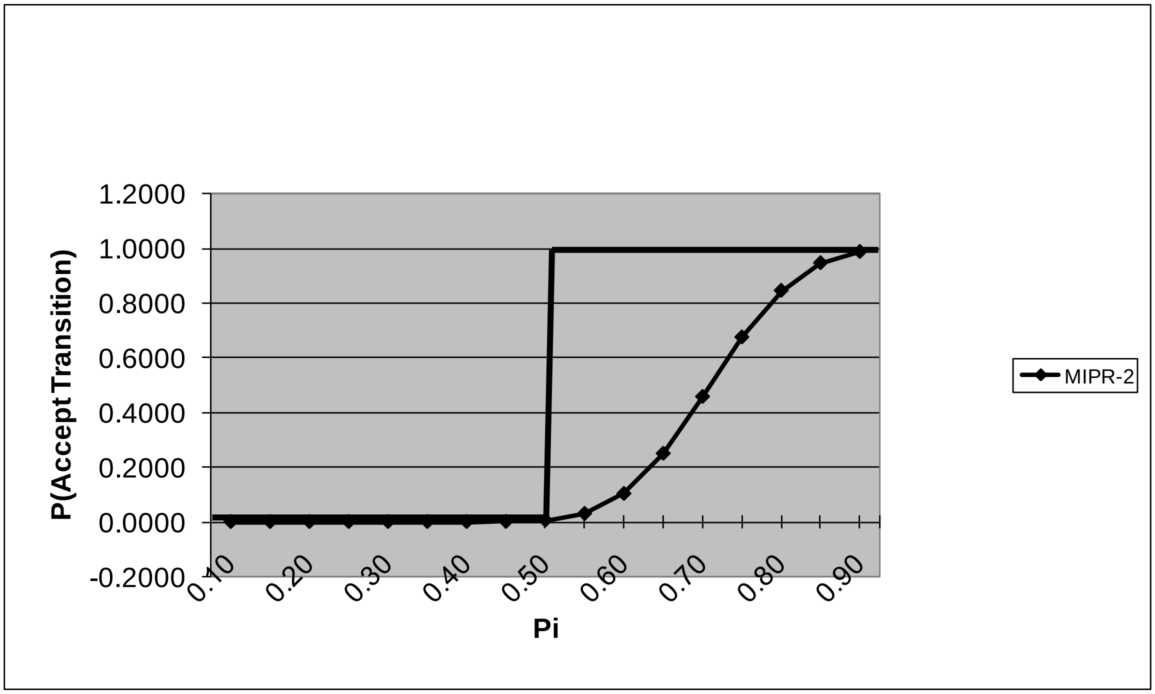


Figure C.55 MIPR-2 with Twenty-Five Respondents ($\alpha = 0.01$ and $\beta \leq 0.99$)

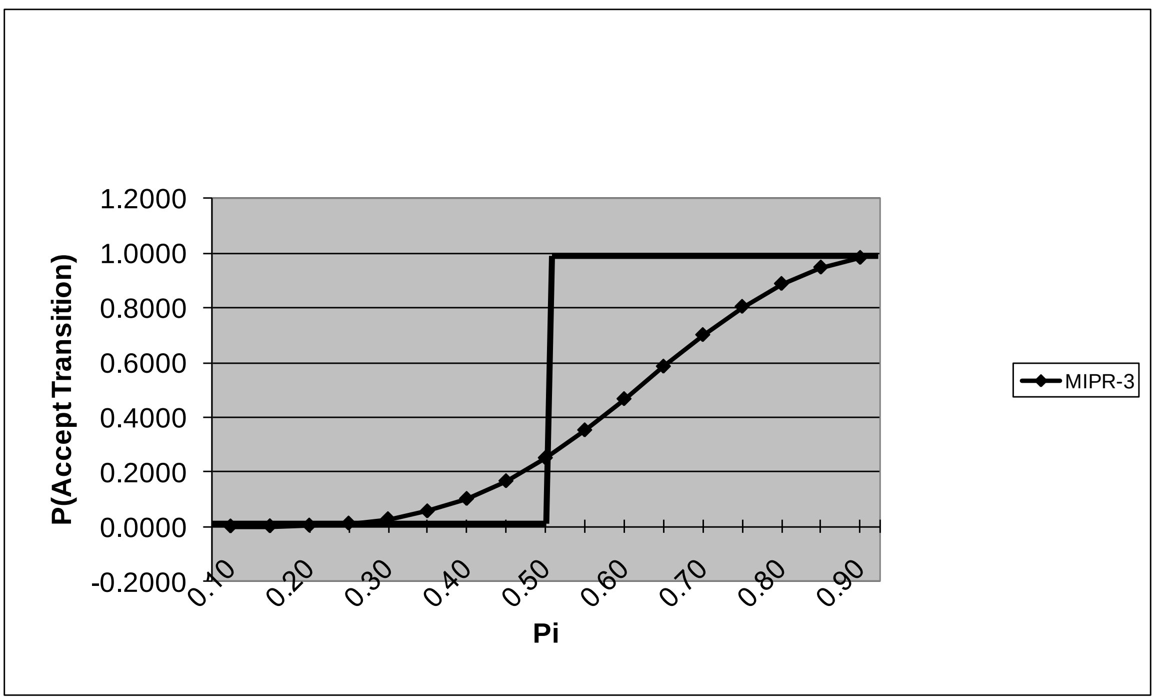


Figure C.56 MIPR-3 with Two Respondents ($\alpha = 0.25$ and $\beta \leq 0.75$)

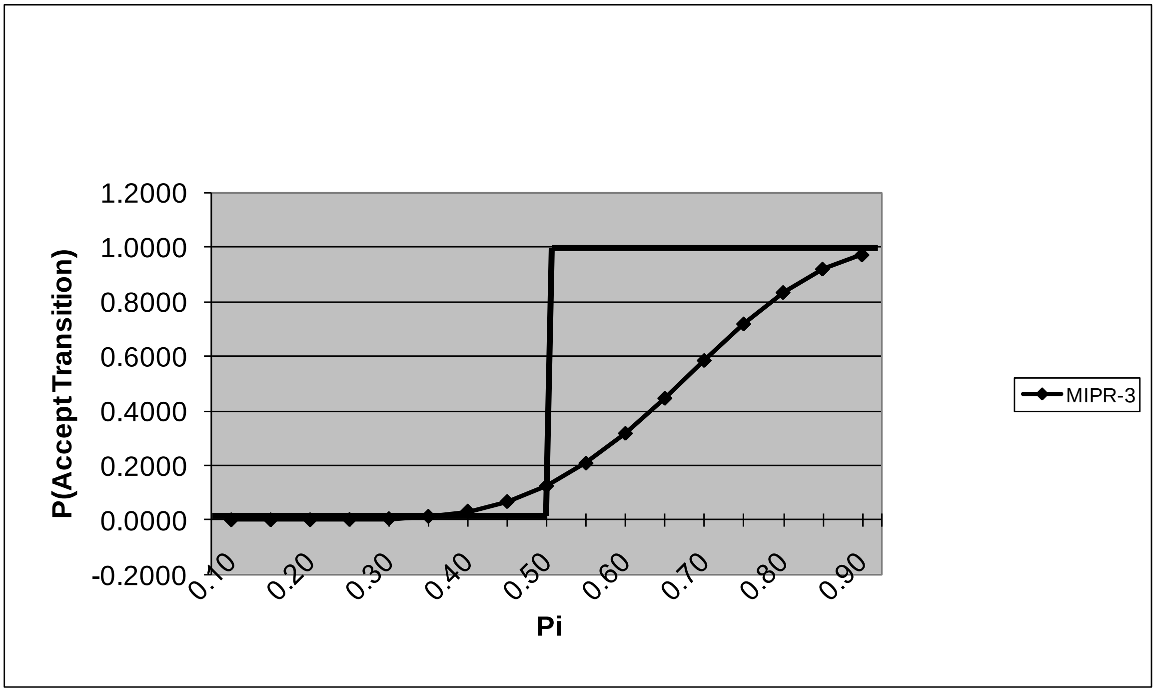


Figure C.57 MIPR-3 with Three Respondents (α = 0.13 and β ≤ 0.87)

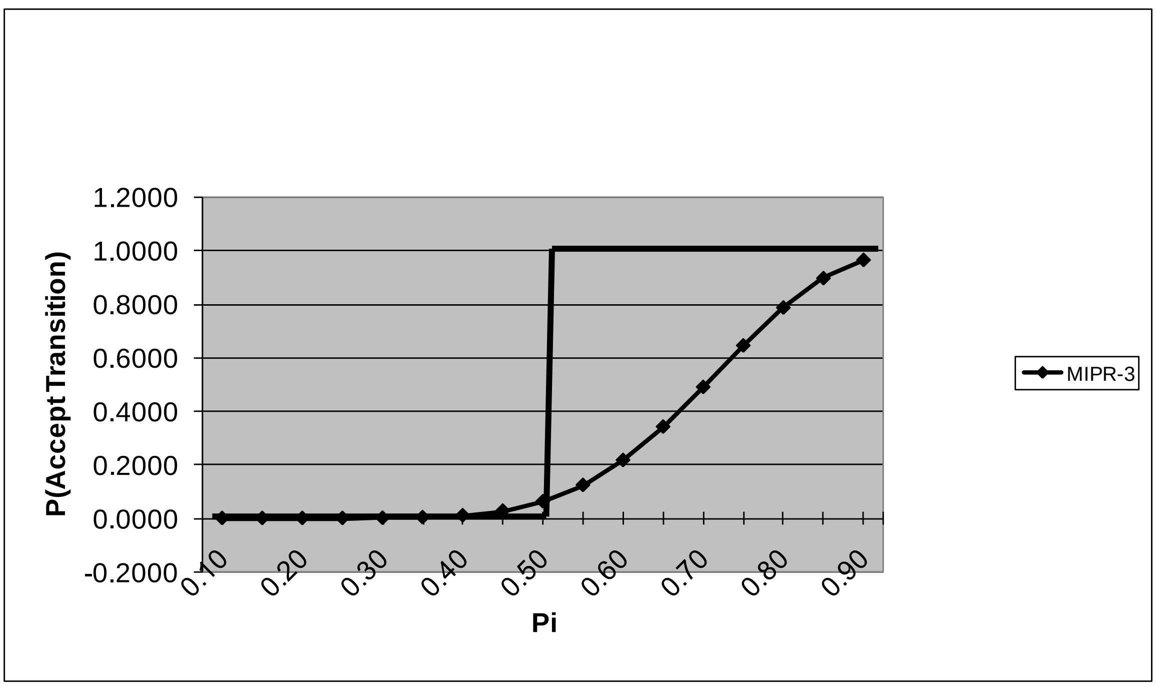


Figure C.58 MIPR-3 with Four Respondents (α = 0.06 and β ≤ 0.94)

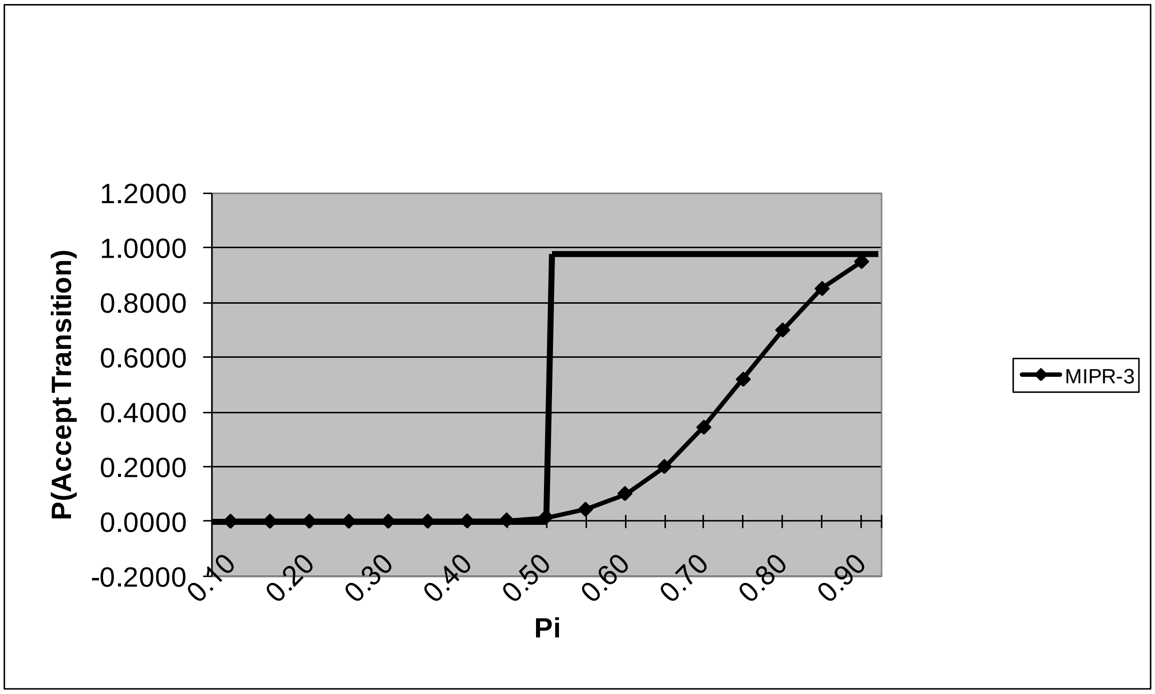


Figure C.59 MIPR-3 with Six Respondents (α = 0.02 and β ≤ 0.98)

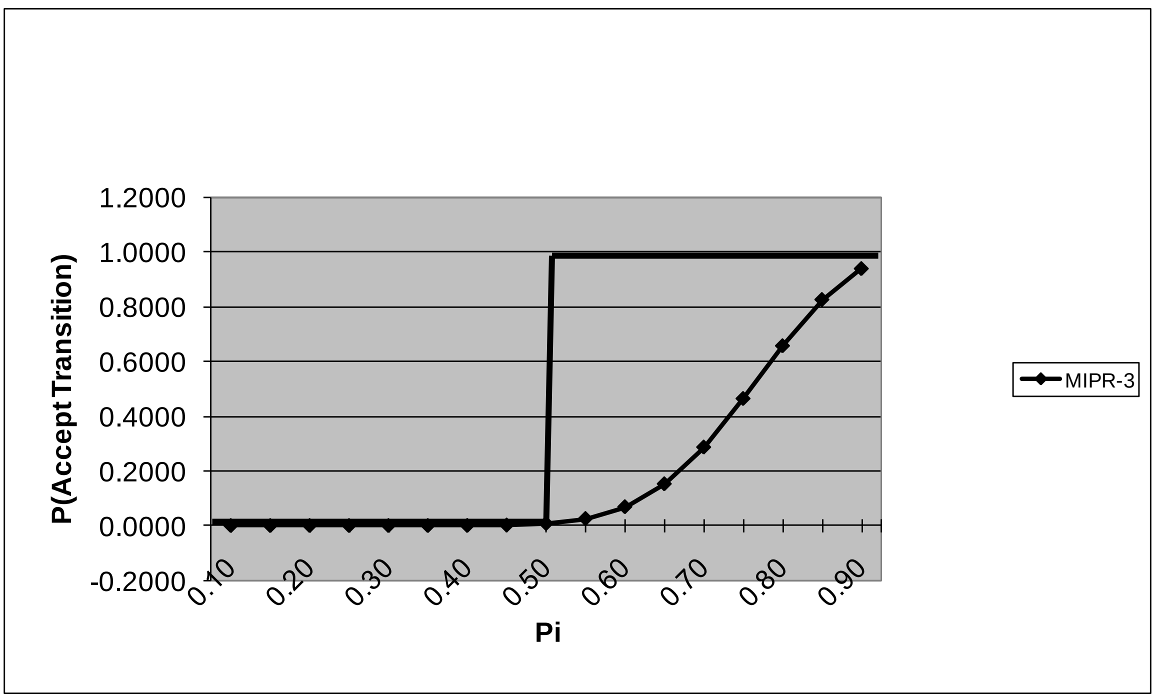


Figure C.60 MIPR-3 with Seven Respondents (α = 0.01 and β ≤ 0.99)

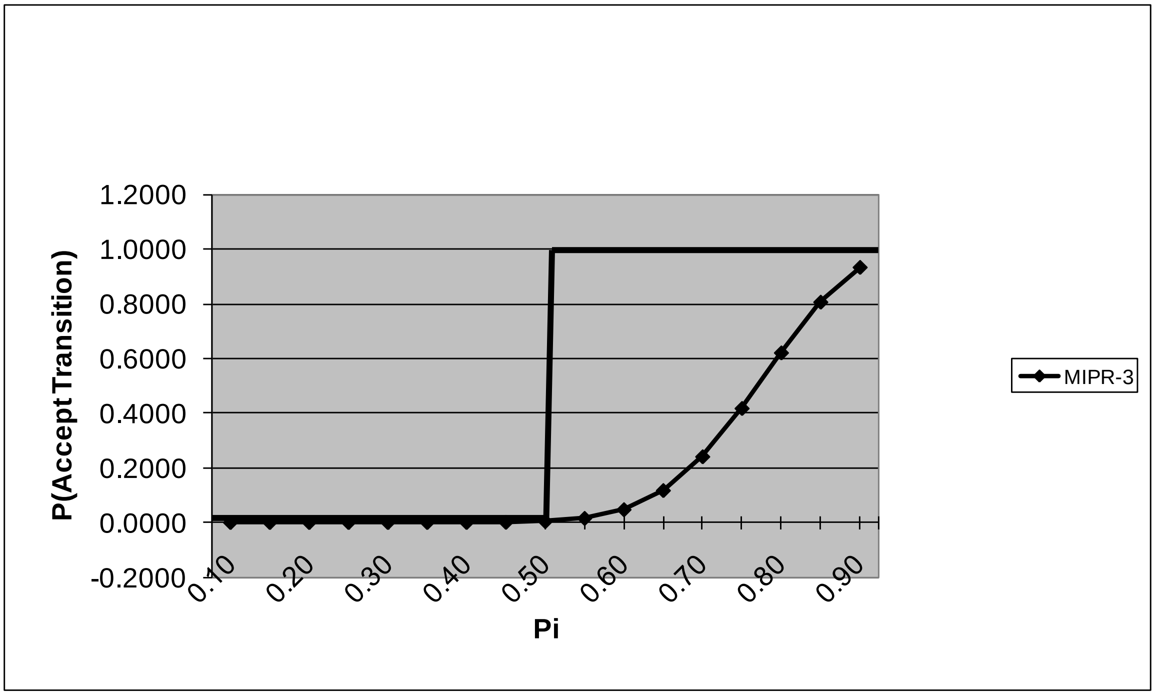


Figure C.61 MIPR-3 with Eight Respondents ($\alpha = 0.00$ and $\beta \leq 1.00$)

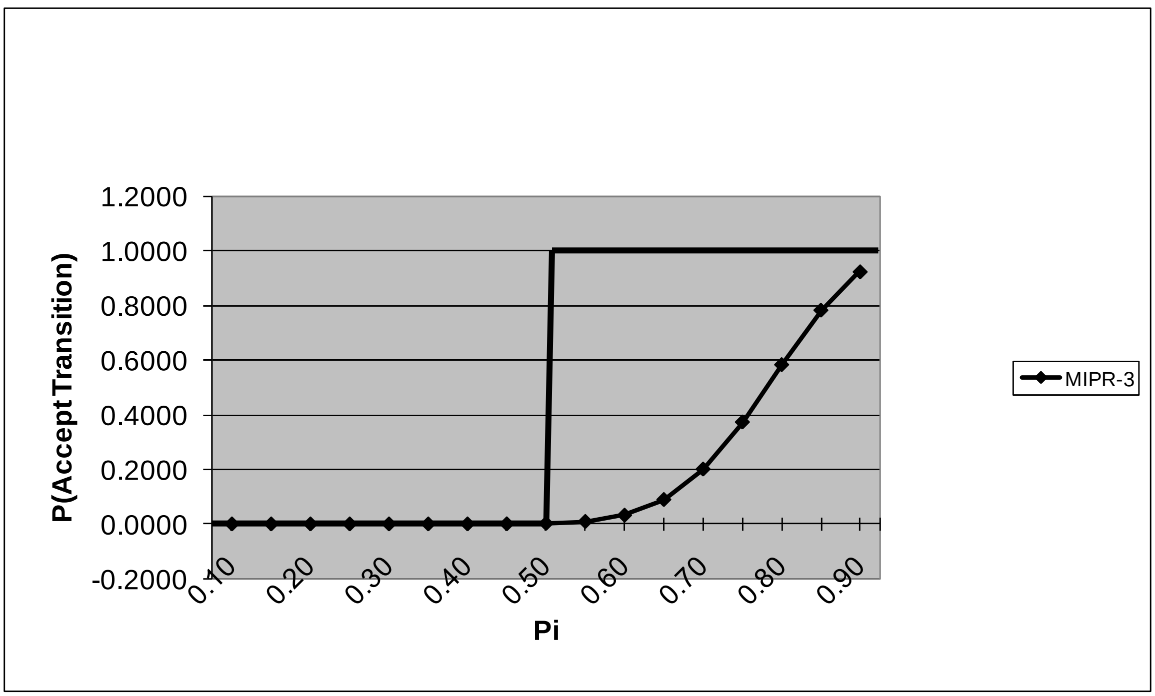


Figure C.62 MIPR-3 with Nine Respondents ($\alpha = 0.00$ and $\beta \leq 1.00$)

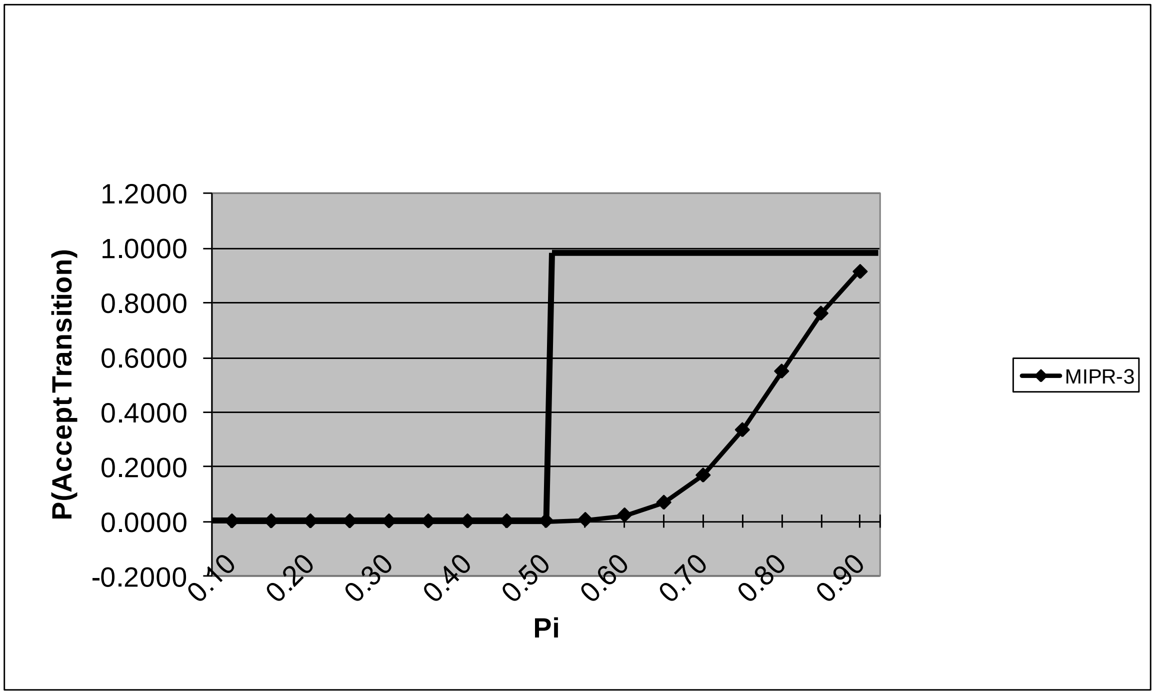


Figure C.63 MIPR-3 with Ten Respondents (α = 0.00 and β ≤ 1.00)

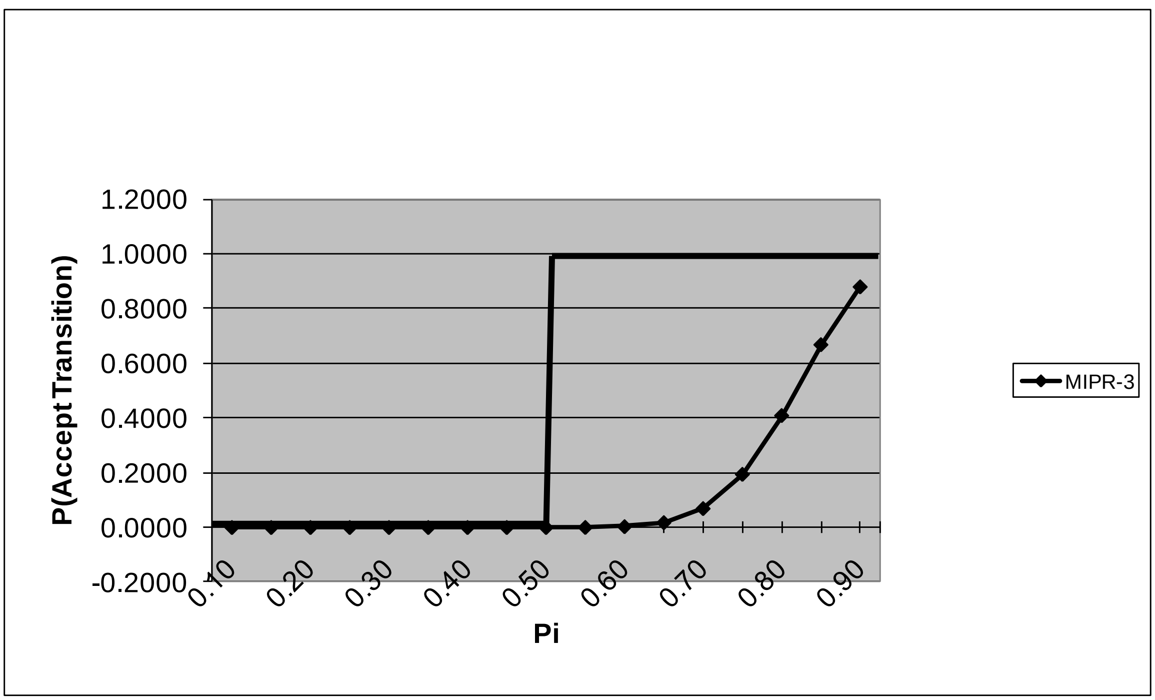


Figure C.64 MIPR-3 with Fifteen Respondents (α = 0.00 and β ≤ 1.00)

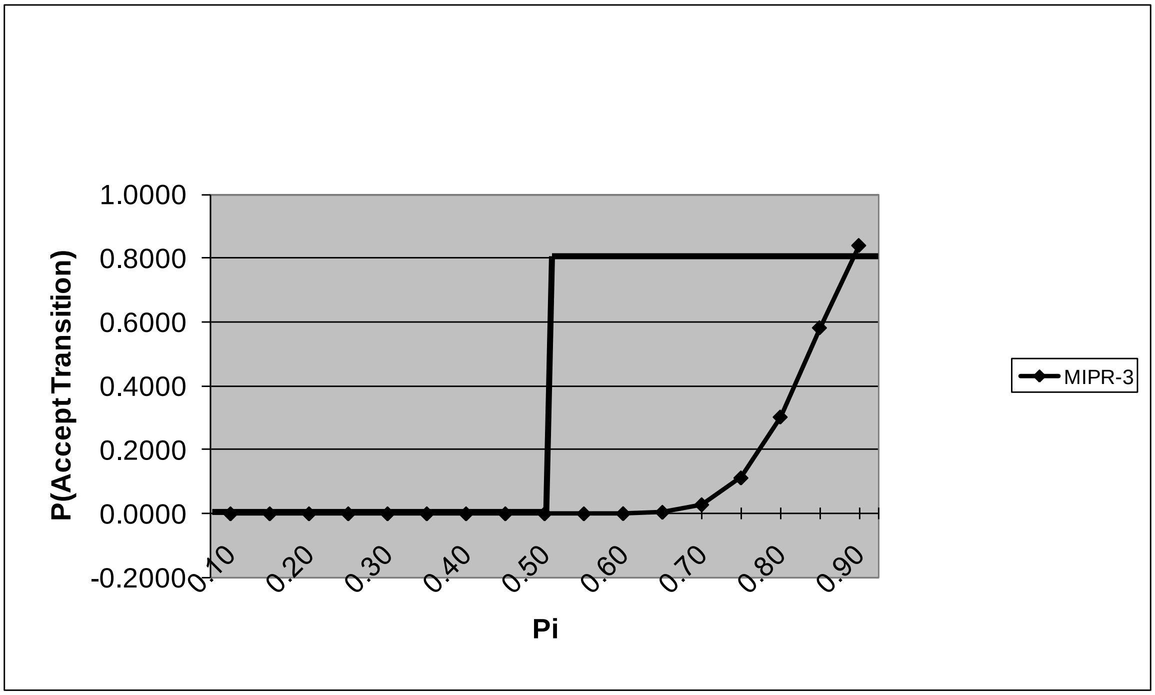


Figure C.65 MIPR-3 with Twenty Respondents ($\alpha = 0.00$ and $\beta \leq 1.00$)

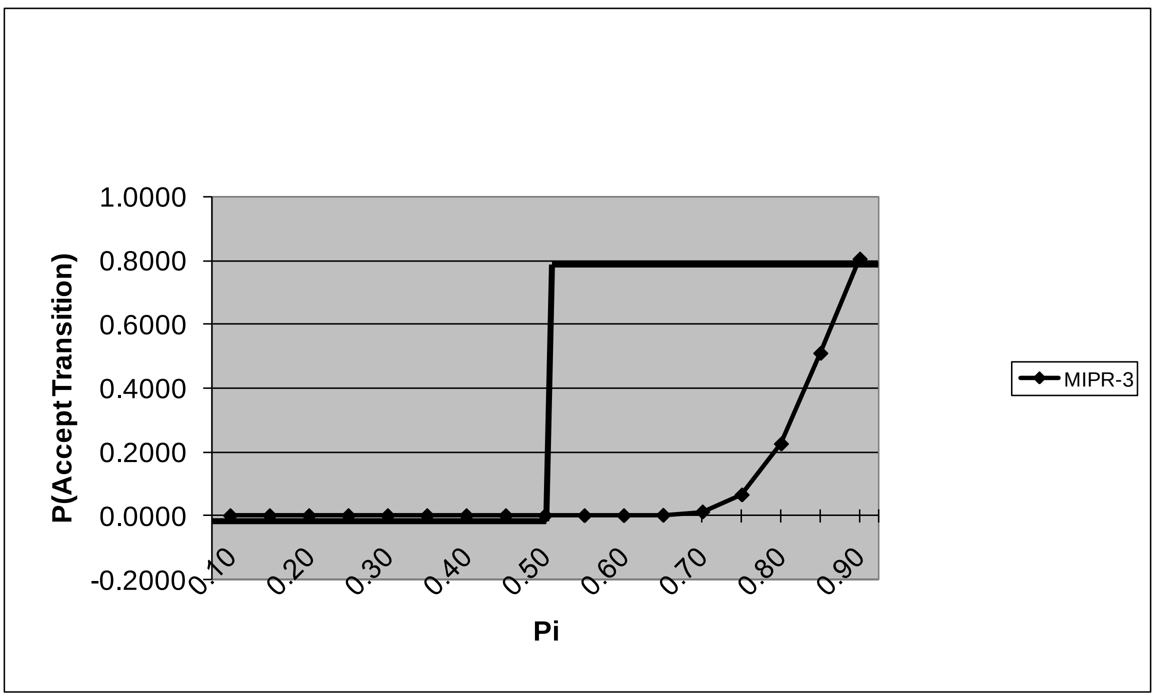


Figure C.66 MIPR-3 with Twenty-Five Respondents ($\alpha = 0.00$ and $\beta \leq 1.00$)

APPENDIX D

ALTERNATE PERFORMANCE CALCULATION

The performance scores of all teams were recalculated to sum (versus average) the individual responses to individual questions in the Halfhill Business and Technology Survey (reference Chapter IV, Sections D and F). Using this alternate performance calculation, the average team score for short term teams that experienced transitions was 21.11 with a standard deviation of 2.60. The average team score for short term teams that did not experience a transition was 20.68 with a standard deviation of 2.20. Using the hypothesis testing methodology as described in Chapter IV:

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 0.77$

Criteria for rejection: $|t_0| > t_{\alpha/2,\, \nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 23.23$

$|t_0| = 0.19 < t_{\alpha/2,\, \nu} = 2.1$ (Conover 1980, Table A3), Fail to Reject

The average team score for short term teams that experienced transitions at the temporal midpoint was 21.50 with a standard deviation of 1.71. The average team score for all other short term teams was 20.67 with a standard deviation of 2.24. Using the hypothesis testing methodology as described in Chapter IV:

H_0: $\mu_1 = \mu_2$; H_1: $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 1.86$

Criteria for rejection: $|t_0| > t_{\alpha/2,\, \nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 17.88$

$|t_0| = 1.86 < t_{\alpha/2,\, \nu} = 2.1$ (Conover 1980, Table A3), Fail to Reject

The average team score for long term teams that experienced transitions was 21.21 with a standard deviation of 2.98. The average team score for long term teams that did not experience a transition was 20.51 with a standard deviation of 2.33. Using the hypothesis testing methodology as described in Chapter IV:

H_0: $\mu_1 = \mu_{2;}$ $H_{1:}$ $\mu_1 \neq \mu_2$, where $\sigma_1^2 \neq \sigma_2^2$

$t_0 = (X_1 - X_2) / (S_1^2/n_1 + S_2^2/n_2)^{1/2} = 0.51$

Criteria for rejection: $|t_0| > t_{\alpha/2,\,\nu}$, where $\alpha = 0.5$ and

$\nu = [(S_1^2/n_1 + S_2^2/n_2)^2] / [(S_1^2/n_1)^2/(n_1+1) + (S_2^2/n_2)^2/(n_2+1)] - 2 = 5.06$

$|t_0| = 0.19 < t_{\alpha/2,\,\nu} = 2.6$ (Conover 1980, Table A3), Fail to Reject

The one long term team that experienced a transition at the temporal midpoint scored 19.0 while all the average team score for all other teams was 20.64 with a standard deviation of 2.41. Since only one long term team was determined to have experienced a transition at the temporal midpoint, a standard deviation could not be calculated. Nevertheless, the performance score of the team that was determined to have experienced a transition was within one standard deviation of the mean performance score of the teams that were determined to have not experienced transitions.

The results calculated by summing individual respondent scores were consistent with the results achieved by averaging individual respondent scores (Chapter V). No statistically significant difference in performance was found between (either short or long term) teams that experienced transitions and teams that did not experience transitions. Furthermore, no statistically significant difference in performance was found between

(either short or long term) teams that experienced transitions at the temporal midpoint and all other teams.

APPENDIX E

DATA

The data used to develop this dissertation is on file with the author. He can be reached at Keith.W.Burleson@nasa.gov or by telephone at 256-975-2307.

The data is also on file in the Industrial and Systems Engineering and Engineering Management Department of the University of Alabama in Huntsville.

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