in H. Zuckerman, J.R. Cole, & J.T. Bruer The Outer Circle: Women in the Scientific Community, New Haven: Yale U. Press 1992

JONATHAN R. COLE / BURTON SINGER

13. A Theory of Limited Differences: Explaining the Productivity Puzzle in Science

THIS ESSAY USES a new general theory of limited differences to propose an explanation for a long established, but poorly understood, pattern of scientific productivity.[1] The theory attempts to explain the empirical fact that male scientists, on average, publish about twice as many scientific papers as their female counterparts, and this disparity increases over the course of careers.[2] Our aim here is to illustrate how a fine-grained explanatory theory of limited differences can account for this. We have chosen the productivity puzzle in science as a strategic research site,[3] but the general theory of limited differences should apply to many other societal patterns of inequality and social stratification—from racial differences in income and occupational prestige over careers to differences in occupational choice among racial and gender groups.

The first section describes the phenomenon to be explained. Section two presents the elements of the theory of limited differences and indicates how the structure of a kick-reaction system can explain the publication process in science. In section three we review prior attempts to explain the gender-differentiated productivity patterns in science. The fourth section formalizes scientific development and the productivity of men and women

J. R. Cole was supported by grants from the National Science Foundation (SES-84-11152), the Josiah Macy, Jr. Foundation, and the Russell Sage Foundation. B. Singer was supported by grant ROI-HD19226 from the National Institute of Child Health and Human Development. Useful comments on earlier drafts were made by Salome Waelsch, Jeremiah Ostriker, Gerald Holton, Stephen Cole, John Bruer, Harriet Zuckerman, Joel Cohen, Margaret Marini and participants at a Macy conference on women in science.

in terms of the theory of limited differences; and in section five we illustrate that process with detailed career constructions from a micro-simulation implementation of the theory. Section six explains how competition among scientists is the driving force affecting the dynamic features of the theory. We conclude with a discussion of testable features of the limited differences theory and outline a research agenda, focusing on measurement problems that must be resolved if the proposed theory is to be further validated or refuted.

The Skewed Distribution of Scientific Productivity and the Productivity Puzzle

Science is a highly stratified institution. A small proportion of scientists hold the lion's share of powerful and prestigious positions as well as honorific awards,[4] and this inequality in rewards is paralleled by equally skewed rates of scientific productivity. That is, the numeric count of published scientific articles and books. Most scientists publish a very limited number of papers; a small percentage publish a great number. Between 10 and 15 percent of all scientists publish about half of all the science produced.[5] This pattern is as true for women scientists as it is for men. The theory of limited differences pertains to all Ph.D. scientists, but since most do not produce more than three or four papers in a career, we intend to concentrate on the elite group of scientists who are the major producers. Therefore, it is this population of primary producers of science, that is, the upper tier of the stratification system, and the factors that influence their rate and amount of production that is the principal focus of this paper.

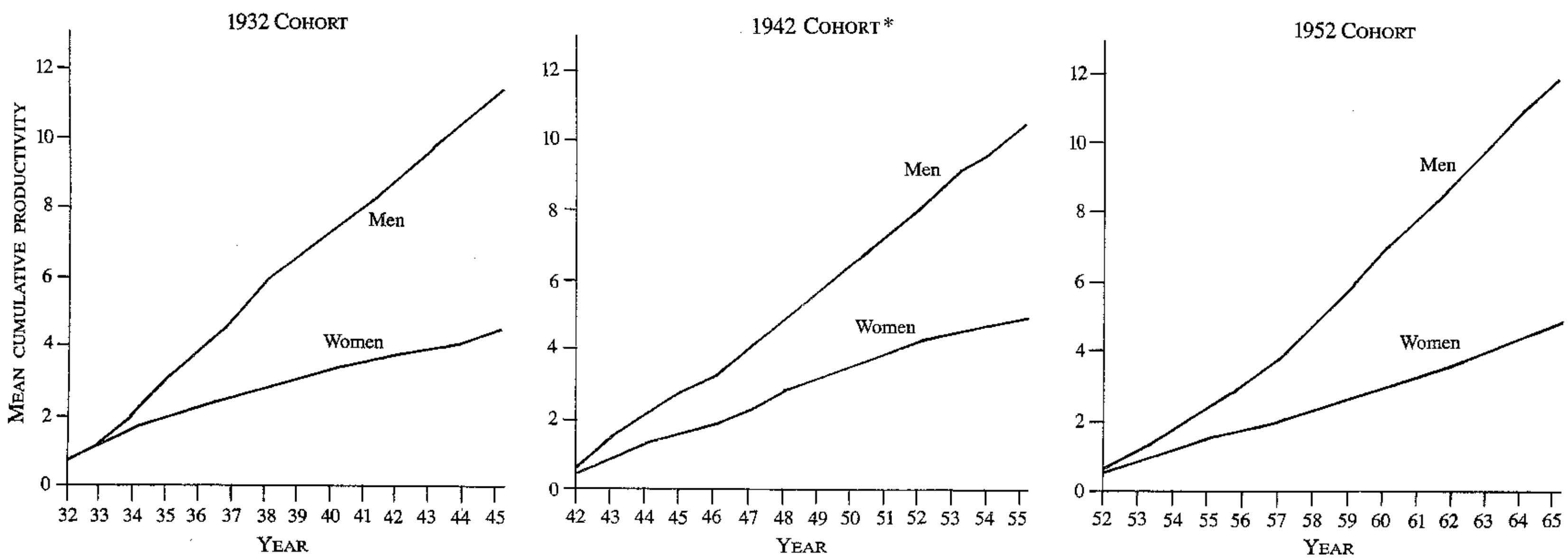
A second pattern of scientific productivity remains poorly understood. Male scientists publish more than females. This sex-related pattern has been demonstrated in more than 50 studies (see Cole and Zuckerman 1984). It is as true today as it was in the 1920s, 1930s, and through the 1960s.[6] To cite but one example, a recent summary of scientific productivity patterns for 526 "matched" men and women who received their Ph.D.s in 1969–70 showed that for the 12 years following their degrees the female mean to male mean productivity ratio was .57 for published papers, .42 for median number of papers.[7] For each type of comparison, the gender difference increases over time (Cole and Zuckerman 1984).[8] Using mean numbers of papers, the ratio of publications of women to men in the first 7 years of the career (i.e., the tenure-relevant years) was .63; for years 8 through 12 it was .51. The ratios of the medians change from .51 for the earlier years to .30 for the later years. This "fanning out" process of sex differences in publications for the 526 scientists and for four cohorts of matched men and women Ph.D.s dating from 1932 to 1957 is illustrated in Figure 13.1.[9] The picture of the 1970 cohort shows that almost all of the fanning action occurs among the top 25 percent of producers. The theory of limited differences attempts to explain these sex differences in scientific productivity.

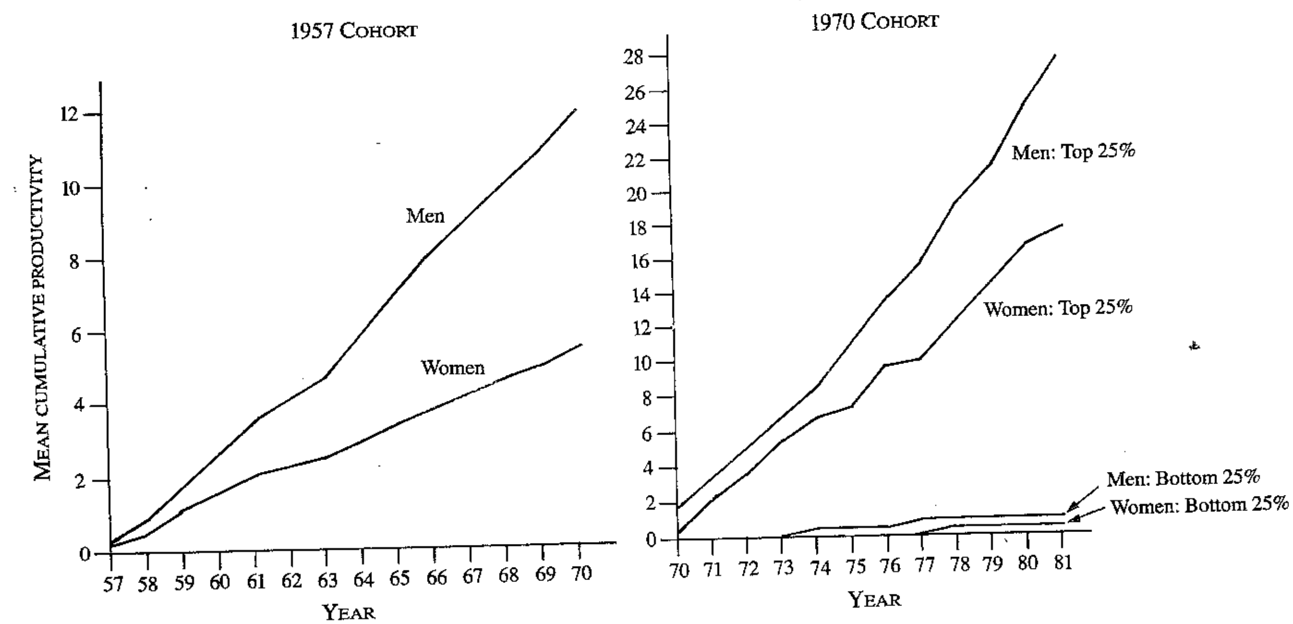
We will also try to explain similarities that have emerged from studies of men and women scientists over the past two decades.[10] For example, there is virtually no association between sex status and: (a) admission to graduate schools of varying prestige or assessed quality; (b) receipt of post-doctoral fellowships; (c) acceptance or rejection of manuscripts submitted for publication; (d) success rates for grant applications; and (e) number of early career honorific awards received. A priori, one might expect that there would be important disparities by sex in early career experiences that would reveal productivity differences within a few years of Ph.D. completion. That this does not occur is what brings forth the notion of a productivity puzzle.

Disparities only emerge gradually. They reveal themselves in *cumulative* numbers of publications, *total* citations to published work, promotion to tenured positions at the most prestigious science departments, and receipt of top honorific recognition, such as Nobel Prizes, Fields Medals, and Lasker Awards. Observations of small fragments in time of the careers of men and women scientists whose initial conditions at the start of graduate school are roughly the same reveal virtually no distinctions in productivity by sex. It is the cumulative, *long-term* nature of the development of productivity and, in turn, reward differentials that represents the challenge for an explanatory theory.

An obvious possible explanation for the gross disparities in productivity exhibited in Figure 13.1 is simply sex discrimination. Although this has undoubtedly played some role—particularly in earlier cohorts—recent focused interviews of men and women scientists[11] revealed that most women indicated that they had not personally experienced discrimination. Nevertheless, most had heard of "other cases" of sex discrimination in science. The theory proposed herein views sex discrimination as only one of many causes of the cumulative productivity differential between men and women scientists. There is partial empirical support currently available for a "limited differences" explanation. Full validation and further refinement of this theory is an important challenge for the future.

13.1 Publication histories for five cohorts of men and women scientists.





*Source: J. R. Cole and H. Zuckerman, "The Productivity Puzzle: Persistence and Change in Patterns of Publication on Men and Women Scientists," in P. Maehr and M. W. Steinkamp, eds., *Advances in Motivation and Achievement*, pp. 217–256. Greenwich, Conn.: JAI Press, 1984.

A Theory of Limited Differences: General Outline

We focus on the dynamics of individuals, each of whom is embedded in a network or networks of relationships constituting the social system of scientific specialties. System dynamics and details of the network structure of science are not part of the present formulation.

Individuals are exposed to a sequence of events of many different types, some or all of which may occur more than once, depending upon the substantive context. There may also be a priori order restrictions in time on some of the events; "acceptance into Ph.D. institution," for example, must occur before "offer of post-doctoral position." Associated with each individual is an outcome variable(s)—e.g., manuscript completions and manuscript publications in a science career setting,[12] annual wages and/or annual income in studies of black-white earnings differentials, scores on age-graded mathematics tests as in studies of U.S. vs. Japanese schools. A "kick-reaction" pair corresponds to each event.[13] Examples, in the context of science careers, of kicks (which may be positive, neutral, or negative) are: acceptance or rejection by a top Ph.D. institution; positive and/or negative funding decisions on grant applications; positive and/or negative publication decisions based on manuscript submissions; marriage to a spouse who either hinders or facilitates the scientist's career. Associated with each kick is a positive, neutral, or negative reaction by the person who experiences it. This reaction acts—almost immediately, or with some delay—with other kicks and reactions to influence the outcome variable(s). Kicks and reactions thus have "memories."

The evolution of events, their associated kick-reaction pairs, and changes in levels of outcome variables are characterized as a vector stochastic process where the conditional probabilities of current state occupancy or changes in state are based on an individual's prior history, subject to the following general constraints:

i) with high probability, the kick-reaction sequences with memory, delays and establishment of competencies for future kicks and reactions determine the outcome variable histories;

ii) with few exceptions, the influence over a short interval of any single kick-reaction pair on an outcome variable will be small (or "limited"). Two individuals with similar, even identical histories up to a given time, but who experience opposite kinds of kick-reaction pairs to any given event—e.g., (negative kick, negative reaction) vs. (positive kick, positive reaction)—will *not* exhibit dramatically different outcome variable dynamics over a short time interval in the immediate future;

iii) all or nearly all kick-reaction pairs influence durations until future events by small amounts. Recurrent events have gently changing duration distributions regulating inter-event intervals. Major changes in waiting-time distributions between events and/or changes in levels of outcome variables will occur over long times or between pairs of events separated by "many" intervening events;

iv) there are a *few* special events for which, in distinguished subpopulations (call them A and B), the probability of a negative reaction to a negative kick for a member of group A exceeds the corresponding probability for a member of group B. Correlatively, the probability of an "improvement" in the outcome variable for an individual with a negative reaction to a negative kick on a special event is less than the corresponding probability for an individual with a positive reaction to a negative kick on the same special event, all other features of the past histories being the same;

v) conditional probabilities of specific changes in outcome variables at a given time are insensitive to the order of occurrence of a subset of the possible events that may have occurred in the past. The specific form of the kick-reaction pairs associated with these events will influence current outcome variable changes; however their order of occurrence will not matter.[14]

When applied to science careers, this general framework implies that cumulative productivity differentials between men and women scientists—identified as group A and B, respectively in conditions *(iv)*—are the result of small—or limited—differences in their reactions to a limited set of kicks. It is the cumulative effect of these small differences that produce, analogous to a "multiplier effect,"[15] major productivity differentials between men and women over a career. Small within-sex differences in a few kick and/or reaction intensities also lead to large career productivity differentials in the population of women scientists alone and among men scientists alone. It is the specific substantive content of the kick-reaction pairs which influences productivity in science and which, more generally, gives specific content to the theory as it is applied to different phenomena.

Consider an example of a career event which is hypothesized to increase slightly the probability that women scientists will be less productive than men. A set of graduate students in physics must select Ph.D. sponsors. All of the faculty in the physics department are men who are willing to sponsor the work of male graduate students; but 10–15 percent of them are unwilling to sponsor female graduate students. This is not an overwhelming disadvantage, but it is a disadvantage nonetheless. It will not affect most women scientists, who would not have wanted to work with that 10–15 percent of reluctant professors in the first place. Most women will not have any experience of a negative kick in the choice of sponsors. However, the entire set of women has a slightly smaller pool of eligible sponsors from which to choose. Some women would have selected these men, but for their refusal to sponsor women. If among these sponsors there are some excellent and powerful scientists, then a small proportion of women students will experience a slight negative kick resulting from not studying with them. The reactions to this kick will vary among the women who experience it. Some will fight even harder against such discrimination; but a subset may have their aspirations dampened and motivation reduced slightly by the experience. Such a difference is small but has clear implications for future events in the careers of the affected scientists and to a limited degree is sex dependent.

Take another illustration. A slightly higher proportion of women than men of roughly equal quality have grant applications rejected for research support of the same size. Consequently, they have fewer resources for their research, less travel money for giving talks, papers, or attending conferences—in short for becoming "visible" to their peers. The sex difference may be limited indeed, but the bias, where it occurs, may decrease slightly these women's productivity potential. In conjunction with prior disadvantages, the somewhat poorer probability of funding reduces the probability of quickly completing manuscripts and publishing papers.

These small negative kicks adversely influence productivity potential in the early phase of the career. They then influence a more significant event, the tenure decision. If tenure is denied, then further negative kicks and reactions can follow, exacerbating still further the difference in productivity potential.

In the case of scientific productivity, the major driving forces behind the manuscript production and publication processes are two interrelated goals: priority for scientific discovery and accompanying peer recognition (Merton 1957); and success in the competition for resources to pursue research at a high level. These primary goals are mediated by the action (kick)-reaction pairs experienced by individual scientists. Positive kicks and reactions are associated with increased incentive and hence with increased manuscript completion and publication. Negative kicks and reactions such as grant rejections and lack of peer recognition—for example, very low use of work by peers—serve as a major disincentive, often leading scientists simply to abandon the race for major scientific discoveries.

Prior Explanations for the Productivity Patterns

Of course, there have been a number of theoretical and empirical efforts to explain the skewed productivity among scientists and the puzzling sex differential. In addition, there are other classes of explanations that have not been applied to this problem but that are plainly theoretically relevant. Most efforts within the sociology of science have focused on three classes of explanations: theories of initial conditions, theories of evolving social processes, and structural constraints.[16] We briefly review these explanations and indicate their relationship to the theory of limited differences.

THEORIES OF INITIAL CONDITIONS: THE SACRED SPARK

Productive scientists, this orientation holds, are those with "a sacred spark," those with the aptitude to tackle and solve difficult problems. While few would question that variations in ability play a formidable role in distinguishing between creative and uncreative science, this position ignores the role of culture, social structure, and personality in contributing to the productivity process. It is problematic primarily because there is simply no evidence to support the claim that gender differences are related either to the initial physiological or to biological conditions that are claimed to result in the productivity differences we are attempting to explain.[17]

THEORIES OF INITIAL CONDITIONS: PSYCHOLOGICAL TRAITS AND SOCIALIZATION PATTERNS

Motivational intensity required for high levels of productivity is assumed a priori in this orientation to be dampened in women because of the formidable early cultural and structural barriers that women face and must hurdle before reaching the starting line for a predominantly "masculine occupation" (Berryman 1983; Kahle and Matyas 1985; Marini and Brinton 1984; Bielby 1991). Socialization processes lead young women to be less confident about their scientific ability, less assertive in advancing their ideas and opinions, less apt to pursue their goals aggressively, while simultaneously being more ambivalent than men about their work and family roles. In due course, women and men come to the starting line for scientific careers carrying baggage of substantially different weights. Differences in scientific production follow naturally from these differences in background and current attitudes and traits. But no mechanism is proposed to explain how these "initial conditions" facilitate or impede subsequent events which unfold during a career—in short, how they are linked to actual productivity. The theory of limited differences as specialized herein to scientific careers does deal with this latter process. It is incorporated in the differential probabilities of positive reactions to negative kicks on special events such as NIH grant decisions.

THEORIES OF EVOLVING SOCIAL PROCESSES: REINFORCEMENT AND SOCIAL LEARNING

Theories of "reinforcement" and "social learning" are based upon observations of the full process of scientific production over a span of years. Reinforcement theory assumes that high levels of initial productivity receive positive reinforcement (through conference invitations, citations, job offers, awards, etc.), which increases the probability of subsequent high scientific productivity (Cole and Cole 1973). Conversely, poor early performance, going unrecognized, is negatively reinforced and leads to lower future production. Social learning theorists hold that individuals' reactions to events, or stimuli, will be influenced both by their past experience with the stimuli, with cognitive processes that influence the perception and retention of the event, and with anticipated future effects of a particular response (Bandura 1986). As Bandura suggests:

> In the social learning theory view, people are neither driven by inner forces nor buffeted by environmental stimuli. Rather, psychological functioning is explained in terms of a continuous reciprocal interaction of personal and environmental determinants. Within this approach, symbolic, vicarious, and self-regulating processes assume a prominent role. (1977: 12–13)

Reinforcement processes and social learning undoubtedly operate to influence manuscript production, but as they have been formulated, they do not specify the emergent structural and cultural properties in social systems that operate to influence manuscript production, specifically sex differentials and the fanning out process. Furthermore, they emphasize the internalized psychological components of action rather than the dynamic structural bases for actions and reactions.

THEORIES OF EVOLVING SOCIAL PROCESS: CUMULATION OF ADVANTAGE

Processes of "cumulative advantage," first articulated by Robert K. Merton (1968), attempt to explain time-bounded patterns of skewed productivity (and recognition) in terms of increased opportunities for scientific resources, both capital and human, that accrue to those who are productive early on—and especially to the productive located at prestigious scientific institutions. Changing distributions of resources become the basis for creating even greater productivity distance between the "haves" and the "have-nots."[18] The cumulative advantage literature has focused on the increasing inequality of scientific publications and citations but has failed to establish the crucial step-by-step linkage between the changing distribution of resources and productivity inequality. The growing inequality has been *assumed* to be the result of cumulative advantages (see Allison, Long and Kraus 1982).

The theory of limited differences, while incorporating the idea of cumulative advantage, is much more fine-grained and specific about the mechanisms which generate productivity differentials. The kick-reaction sequences are the primitive ingredients in the theory of limited differences; there is no comparable *explicitly formulated* mechanism for the evolution of individual careers in the extant literature on cumulative advantage. In addition, the fact that reactions to particular events are allowed to depend upon prior events, past kick-reaction pairs, and initial conditions is what allows us to integrate socialization processes, psychological theory, and cultural value systems explicitly into the evolutionary dynamics of the limited differences formulation.

Furthermore, in the case of the scientific productivity differential between men and women, the theory of limited differences, through analysis of the sequencing of kick-reaction pairs, suggests a method for assessing whether or not one group rather than another will ultimately monopolize resources, rewards, and the productivity process. The theory allows us to determine the extent to which one group or another "dominates" the distribution of specific positive or negative kicks, and analysis of reaction systems enables us to identify differentiated responses by men and women to similar positive and negative career events.

STRUCTURAL CONSTRAINTS

Sex discrimination has been used to explain the sex differences in publications, and undoubtedly it has been a source of structural constraint for women scientists. Differential opportunities based on sex, or on other individual attributes that are unrelated to performance, can be translated into competitive advantages in the acquisition of resources and facilities necessary for high productivity.[19] In fact, discrimination, whether based on sex, religion, national origin, age, or race, enters the theory as a significant substantive element in determining limited differences.

But discrimination is viewed here as one among many sources of structural constraints affecting publication probabilities. For example, women's domestic responsibilities associated with child-bearing and child-raising could account for the lower rate of productivity of women scientists. This hypothesis has been studied in some detail. It turns out that women with children are as scientifically prolific, on average, as those without them (Cole 1979; Cole and Zuckerman 1987). But a small subset of women, distinctly limited in number but greater than the number of men, are adversely affected by building families, and this represents a limited difference that will influence productivity for that small subgroup. Thus, marital and fertility histories are a central feature of the application of limited differences dynamics to science careers.

Since scientific production is almost invariably carried out within social organizations, these organizational contexts can influence the form and substance of productivity. Some environments may be conducive to research; others hostile to it—and this holds for all scientists. But there may also be organizational structures that limit the productivity of women more than men. These range from barriers to participation to subtle exclusions from informal interaction within laboratory settings (Bielby and Baron 1984; Fox 1981a; Long 1978; Pfeffer 1982; Reskin 1978a,b). Only a rough beginning at empirical research aimed at measuring the actual effects of organizational structures on scientific productivity has been carried out (see Long and McGinnis 1981). These studies have been unable as yet to specify adequately how dynamic interactive processes between the "environment" and the individual influence productivity and, more specifically, what features of organizational environments adversely affect women's productivity relative to similarly situated men.

There are, then, a set of existing social and social psychological theories that purport to explain gender differences in scientific productivity and the fanning out process. Each of these theories has useful elements, but individually they take us only a limited way toward explaining the productivity patterns in question.[20] Aspects of each are incorporated into the theory of limited differences. We turn now to a description of basic elements in the theory and to its application to solving the productivity puzzle.[21]

Formalization of Science Career Development

We specialize and interpret the general outline of the theory given above in the context of science careers.

A PRIMARY EVENT LIST AND DELINEATION OF INITIAL CONDITIONS

A set of career events, hypothesized to be the basis of an explanation of the productivity puzzle in science, is listed in Table 13.1. This is by no means an exhaustive list; however, it does contain the items which both empirical studies to date (see, among many others, Astin 1969; Astin and Bayer 1972; Bayer and Astin 1972; Centra 1974; Clemente, 1973; Cohen 1980; Crane 1969; Cole and Cole 1973; Gaston 1973; Hagstrom 1971; Hargens, McCann and Reskin 1978; Helmreich et al. 1980; Spence, Helmreich and Stapp 1975; Spence and Helmreich 1978, 1979; Zuckerman 1977, 1989; Cole 1979; Allison and Stewart 1974; Long and McGinnis 1981; Cole, Rubin and Cole 1978; Cole, Cole and COSPUP 1981; Reskin, 1977, 1978a, 1978b; Zuckerman and Merton 1971a, 1971b; Zuckerman and Cole 1975; Over 1982; Over and Moore 1980) and prior theoretical proposals suggest should be the most important events.

TABLE 13.1 *Events Influencing Scientists' Productivity Histories*

E_1 = Decision on Ph.D. institution
E_2 = Decision on Ph.D. sponsorship
E_3 = First post-doctoral job or post-doctoral fellowship
E_4 = Publication decision: acceptance or rejection of paper
E_5 = Marriage or cohabitation
E_6 = Birth of child
E_7 = Perceived quality of research: critical reception of publications
E_8 = Funding decision
E_9 = Marital disruption or cessation of cohabitation
E_{10} = Tenure decision
E_{11} = Moderate honorific recognition (e.g., Guggenheim, Sloan fellowships)
E_{12} = Major honorific award (e.g. Lasker, NAS membership, Fields Medal, Nobel Prize)
E_{13} = Laboratory directorship
E_{14} = Job offer from outstanding department
E_{15} = Critical reception of paper prior to publication

Note: For each event E_j, there will be nine logical combinations of kick-reaction pairs.

There are some a priori order restrictions to be imposed on these events which indicate that some of them must occur in time prior to others. Introducing the relation < to mean "before," we require:

(i) $E_1 < E_2 < E_3 < E_{10}$

(i.e., acceptance into Ph.D. institution must occur *before* acceptance of Ph.D. sponsorship, which, in turn, must occur before a tenure decision.)

(ii) $E_5 < E_9$
(iii) $E_5 < E_6^{(1)} < \ldots\ldots < E_6^{(m)}$ ($E_i^{(j)}$ means j^{th} occurrence of i^{th} event)
(iv) $E_2 < E_{11}^{(1)} < \ldots. < E_{11}^{(v)}$
(v) $E_{11}^{(1)} < E_{12}^{(1)} < E_{12}^{(2)} \ldots.$
(vi) $E_{15} < E_4 < E_7$

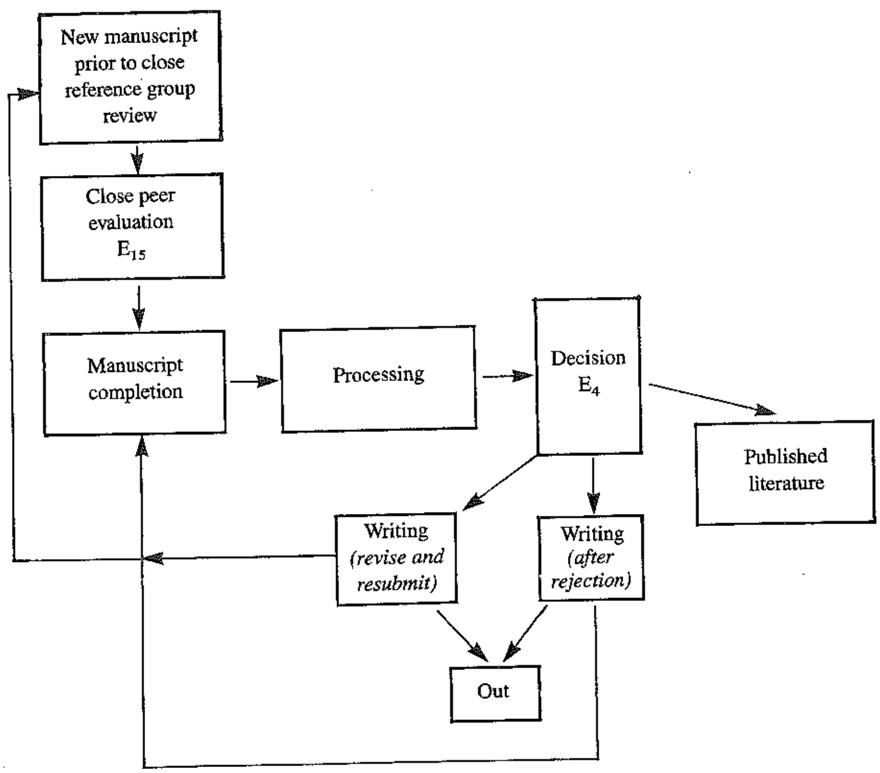
With the exception of these constraints, any ordering of events is possible in principle. Science careers will be assumed to start when an individual applies to a graduate program in some scientific field or specialty. The details of the process of self-selection which leads some individuals to this choice, as opposed to other career options, is an important topic which lies outside of the scope of the present formulation. Thus gender differences in early socialization and a variety of attitudes and expectations about what is or is not achievable in a scientific career will be assumed to be the primary source of variation across individuals when the career process initiates. Persons clearly differ in basic ability and motivation even when initially self-selecting to begin a science career; however, there are, as yet, no good measures of early ability and motivation which distinguish men from women at this stage. There are also no effective *early* screening measures which will indicate who among persons in the same discipline, prestige level of graduate school, and with comparable undergraduate record are likely to be the major producers of science in their cohort.

OUTCOME PROCESSES

Two interrelated outcome variables will be central to the present specification of science careers: manuscript completions and publications. These variables are related in a publication process as delineated in Figure 13.2.

When drafts of manuscripts are generated, they are frequently circulated among close peers for comment and criticism—this gives rise to the event, E_{15}. Following this event, manuscripts are completed and, with high probability, are submitted to journals for review, thus leading to a publication decision—the event E_4. A favorable decision is followed by a manuscript publication. However, an unfavorable decision puts manuscripts into a feedback loop which may lead to a revised manuscript completion and a subsequent publication or may lead to the scientist simply giving up on the paper. The process exhibited in Figure 13.2 has separate compartments for "writing following an outright rejection for publication" and "writing following an editor's request for some revisions" because of the very different attitudes that scientists will have while in each of these regimes. This distinction then leads to different probabilities of manuscript completions and resubmissions, an important feature of a science career.

The probabilities associated with transitions along various paths in this set of events vary dramatically by field, specialty, and even research area. For example, the probability of publication given an initial submission in virology is approximately .9 or roughly .75–.9 in physics, while the same conditional probability is roughly .2–.3 in some subspecialties of sociology and economics.[22] Such differentials are apt to lead to different expectations by scientists in varying fields and hence to different intensities of reactions to rejected manuscripts.[23] Thus the (submission → publication) link is primarily subject-matter determined while the (peer evaluation → completion), (completion → submission), (revision → submission), and (rejection → revision → submission) paths are much more heavily influenced by individual drive, motivation, and career aspirations.



13.2 The process of scientific publication.

KICK-REACTION PAIRS

With each event from the list in Table 13.1, as it occurs in an individual's evolving career, there is associated a kick-reaction pair. Kicks and reactions can each be of three kinds: positive, neutral, and negative.[24] We will denote these alternatives by the system of symbols:

KICKS	REACTIONS
k^+ = positive kick	r^+ = positive reaction
$k^\cdot$ = neutral kick	$r^\cdot$ = neutral reaction
k^- = negative kick	r^- = negative reaction

Thus for each event there are nine possible kick-reaction pairs. The probabilities of occurrence of pairs such as (k^+, r^+) and (k^-, r^-) will be substantially larger than the probabilities associated with, for example, (k^+, r^-), (k^-, r^+), and $(k^\cdot, r^-)$. A given kick-reaction pair will influence the outcome variables through conditional probability distributions whose structure is described in the next section. In addition, the probability distribution on kick-reaction pairs associated with a given event will depend on an individual's kick-reaction history and outcome history prior to the event in question.

There is a strong social psychological component to the reactions associated with particular kicks in the form of increased or decreased motivation. Motivational differences result not only from psychological sources but also from processes of socialization and social structure. Differences in socialization between men and women can lead to some differences in individual traits such as aggressiveness, competitiveness, self-confidence, degree of confidence, and comfort in an environment in which the individual represents a minority (Duncan and Duncan 1978; Maccoby and Jacklin 1975; Marini 1987). These may produce small sex differences in the distribution of expectations, aspirations and motivation and somewhat different tolerance and resistance to negative events. In short, differences in reaction systems of men and women scientists may result from socialization processes. These processes are hypothesized to produce empirically identifiable differences in the reaction systems of men and women scientists. Most men and women scientists may "look alike" in terms of their reaction systems, if for no other reason than that self- and social selection processes lead to these similarities. However, scientists, male or female, with different types of reaction systems will respond in varying ways to the same kick. The actual impact of a kick depends upon the reaction to it.

Reaction systems, of course, also affect behavioral outcomes in an anticipatory way: fear of rejection forestalls action and produces avoidance behavior. Reaction systems affect and are affected by the cognitive styles of scientists. Some scientists will be risk-adverse, fearing negative kicks. Others opt for tackling risky problems and take chances in their efforts to be published in the top journals, or to be optimally funded for their research.

There are also structural constraints on flexible reactions to kicks that have little to do with psychological traits. Clearly, scientists in different social structural locations have differential opportunities to react positively or negatively to kicks (Fox 1983). Some are in situations where they can "do something about" a negative kick, others are not. Institutional structures not only affect reactions to kicks but influence the sequencing of future kicks and the duration of time between manuscript completions.

Social and cultural customs and mores, such as marital patterns, also can constrain types of reactions to kicks, as is the case when the geographic mobility of a woman is restricted by her spouse's job (Marwell, Rosenberg and Spilerman 1979). Ceterus paribus, women scientists are more apt than men to be structurally constrained in their choices. For both men and women the sequence of reactions to the same or similar events will change with successive kicks.[25] In particular, the resiliency of positive or neutral reactions will diminish with a succession of negative kicks.

PROBABILITY SPECIFICATIONS AND MEMORY EFFECTS

We represent science careers in terms of: (a) a sequence of early events—in particular, those which occur up to the first post-Ph.D. position—where there is an accumulation of kicks and reactions which strongly influence subsequent mid-career development; (b) the period from first job beyond the Ph.D. to first major award (this is where the basic publication record is established); and (c) the post-initial major award period, where substantial publication is reinforced, accelerated because of growing resources, or dampened because of increased obligations outside of the research role. Many scientists, even among prolific producers, will never move to phase c, but large proportions of those traveling in this fast lane will receive substantial honorific recognition.[26]

The Early Events Module

We consider the events E_1, E_2, and E_3 which are, of course, constrained by the order relation $E_1 < E_2 < E_3$. In addition, the events E_4, E_5, E_6, E_8, and E_9 may be interdigitated with $E_1 - E_3$ subject also to the order restriction listed on p. 289. Early event histories will consist of sequences of three or more events from the above list, and E_1, E_2, and E_3 must occur in each sequence. We denote by $|E_1$, $|E_2$,.... the possible *sequences* made up of at most the above eight distinct events subject to order restrictions and allowing some events, such as birth of a child (E_6), to occur more than once prior to E_3.

For example, we may set

$$|E_1 = \{E_1, E_2, E_3\}$$
$$|E_2 = \{E_5, E_1, E_6^{(1)}, E_2, E_3\}$$
$$|E_3 = \{E_1, E_2, E_5, E_3\}$$

.

.

.

.

Then within sequence $|E_i$ we denote the kick-reaction pairs by $(K_{j_1}^{(|E_i)}, R_{j_1}^{(|E_i)}), (K_{j_2}^{(|E_i)}, R_{j_2}^{(|E_i)}), \ldots$ where j_1 is identified with the subscript of the first event in $|E_i$, j_2 is identified with the subscript of the second event in $|E_i \ldots$, etc. For example, in sequence $|E_2$, $j_1=5$, $j_2=1$, $j_3=6$, $j_4=2$, and $j_5=3$.

With this notation at hand we represent the joint distribution of events and kick-reaction pairs as the product of conditional probabilities

$$\text{Prob}\,(|\vec{E}_i;\quad (K_{j_1}^{(|E_i)}, R_{j_1}^{(|E_i)}), \ldots, (K_{j_\mu}^{(|E_i)}, R_{j_\mu}^{(|E_i)})) \tag{1}$$

$$= \prod_{l=0}^{\mu-1} \text{Prob}\,((K_{j_{\mu-l}}^{(|E_i)}, R_{j_{\mu-l}}^{(|E_i)}) \;\Big|\; \begin{matrix}\text{kick-reaction pairs}\\ \text{prior to event } j_{\mu-l}\end{matrix};\quad |E_i)\ \text{Prob}\,(|E_i)$$

where μ = number of events in $|E_i$

Each kick-reaction pair can assume any one of the nine possible values (k^+,r^+), $(k^\cdot,r^+)$, (k^-,r^+), $(k^+,r^\cdot)$, $(k^\cdot,r^\cdot)$, $(k^-,r^\cdot)$, (k^+,r^-), $(k^\cdot,r^-)$, and (k^-,r^-). Numerical specification of Prob($|E_i$) is guided by empirical frequencies in existing surveys of scientists. The general conditional probabilities in equation (1) must be further restricted to conform to particular proposals about the influence of memory on current perceptions of kicks and associated reactions. Two specifications which are relevant for science careers are:

(A) For a given sequence, $|E_i$, past kicks and reactions prior to the 1^{th} event influence the probability of the 1^{th} kick-reaction pair only through the sums

$$\sum_{m=1}^{l-1} W_{j_m}^{(|E_i)} \operatorname{sgn}\,(K_{j_m}^{(|E_i)})$$
$$\text{and} \tag{2}$$
$$\sum_{m=1}^{l-1} V_{j_m}^{(|E_i)} \operatorname{sgn}\,(R_{j_m}^{(|E_i)})$$

where

$$\operatorname{sgn}\,(K_{j_m}^{(|E_i)}) = \begin{cases} +1 & \text{if}\quad K_{j_m}^{(|E_i)} = k^+ \\ 0 & \text{if}\quad K_{j_m}^{(|E_i)} = k^\cdot \\ -1 & \text{if}\quad K_{j_m}^{(|E_i)} = k^- \end{cases}$$

and

$$\operatorname{sgn}\left(R_{j_m}^{(|E_i)}\right) = \begin{cases} +1 & \text{if } R_{j_m}^{(|E_i)} = r^{+} \\ 0 & \text{if } R_{j_m}^{(|E_i)} = r^{\cdot} \\ -1 & \text{if } R_{j_m}^{(|E_i)} = r^{-} \end{cases}$$

The weights $\{W_{j_m}{}^{(|E_i)}\}$ and $\{V_{j_m}{}^{(|E_i)}\}$ indicate the relative influences of past events on the probability of a current kick-reaction pair. The weight sequences are associated with specific orderings of events—namely, $|E_i$—and need not be invariant under permutations of them. The parameterization (2) implies that the full past influences current probabilities—if all weights are non-zero—and that the longer the sequence the less influence any single kick-reaction pair in the past will have.

(B) If an early event and its kick-reaction pair only influence a specific future event, this effect is captured in the specification

$$\begin{aligned} &\text{Prob}\left((K_l^{(|E_i)}, R_l^{(|E_i)}) \mid \text{kick-reaction history prior to } l^{\text{th}} \text{ event}\right) \\ &= \text{Prob}\left((K_l^{(|E_i)}, R_l^{(|E_i)}) \mid (K_j^{(|E_i)}, R_j^{(|E_i)})\right) \end{aligned} \quad (3)$$

for a distinguished event—the j^{th} event—occurring at an earlier time, $j < 1$. An example of this is where the j^{th} event is "marriage by a woman scientist in undergraduate school" but to a man whose career imposes rigid geographical immobility for the couple. In terms of the event sequence formalism, this is a history for which $E_5 < E_1$. Now we define the 1^{th} event to be E_3 = (offer of first post-doctoral position) and assume that the position is at an outstanding institution—thereby giving rise to a positive kick—but that it is located outside the geographical range which would preserve the husband's job. Thus a negative reaction is associated with the positive kick—i.e., $(K_1{}^{(|E_i)}, R_1{}^{(|E_i)}) = (k^+, r^-)$. The marriage itself, at the time of its occurrence, is associated with $(K_j{}^{(|E_i)}, R_j{}^{(|E_i)}) = (k^+, r^+)$. The dependency restriction (3) implies that all events other than the marriage have no influence on the current kick-reaction pair. The idiosyncratic detail of geographic immobility of a spouse is not formally incorporated in the probability specification; however, non-zero conditional probabilities for the sequence of kick-reaction pairs

$$(K_j^{(|E_i)}, R_j^{(|E_i)}) = (k^+, r^+) \rightarrow (K_l^{(|E_i)}), R_l^{(|E_i)}) = (k^+, r^-) \quad (4)$$

are interpreted to mean that some major obstacle associated with the marriage gave rise to the negative reaction on the 1^{th} event.

Mid-Career Dynamics

Development of manuscripts for publication usually begins prior to Ph.D. completion in the sciences and, in some fields, even in undergraduate colleges. We assume that once the manuscript completion process begins, new manuscripts are produced at independent but not identically distributed intervals until the start of a first post-doctoral position. Kicks and reactions in the early events module are not assumed to influence manuscript completions prior to receipt of the Ph.D. degree. However, kicks and reactions in the feedback loop of the publication process—Figure 13.2—will slightly increase the manuscript completion rate when positive reactions occur and slightly decrease it when negative reactions occur.

Once the first post-Ph.D. position is attained, then the waiting times between successive manuscript completions have means and variances which are functions of the cumulating kick-reaction experience to the full range of events listed in Table 13.1. These means and variances decrease slightly with each positive reaction and increase with negative reactions. Thus, the intermanuscript completion intervals are decomposed into episodes separated by occurrences of events outside the publication module, and, condition on the kick-reaction pairs associated with these events, the conditional mean and variance of the waiting time distribution for manuscript completions is adaptively altered.

The cumulative number of manuscript completions and publications as well as their rate of occurrence in particular time intervals influences the probability of kick-reaction pairs on special events such as grant decisions and major and minor awards. Indeed in the post-Ph.D. regime, events occur in a continuously evolving stream where the inter-event time intervals and the character of the associated kick-reaction pairs is governed by the prior kick-reaction history and the productivity record. Qualitatively, r^+ reactions and increasing manuscript completions increase the probability of (k^+,r^+) on future events and the probability of r^+ when k^- occurs. Thus past success generates resilience to future negative kicks, such as grant rejections. Waiting times until occurrence of both minor and major awards[27] also depend on productivity and citation ranking of the individual scientist among peers in his (her) subspecialty. For minor awards, the higher the ranking on at least one of these variables, the shorter the expected waiting time until reception of awards and the shorter the expected duration between successive awards.

Major awards in most scientific fields are dominated by the most prolific and visible scientists—perhaps the top 10 percent. Major awards, such as Nobel Prizes, have a ratchet effect. Upon receipt of one, the influence of past history on the durations between manuscript completions is reset to a "post-award" level and no longer depends significantly on the earlier kick-reaction history.

Beyond the First Major Award

There is considerable variation in reactions by scientists to the receipt of major awards. Some continue research at an increased pace; others leave the laboratory altogether; still others have temporary reductions in scientific productivity followed by reestablishment of a prolific rate of publication.[28] Those who shift into administrative roles have dramatically reduced manuscript completion rates; their publication probabilities are assumed to be unrelated to past kick-reaction histories. For those continuing research as their primary activity, the previous reaction history no longer really influences manuscript completion rates. After receiving major awards, the primary influences in manuscript completion rates are assumed, a priori, to be kicks associated with grant rejections. Eminent scientists are not immune to negative peer reviews, lower than expected priority scores, and rejections of grant applications. While they tend to submit more proposals than their less distinguished colleagues, they generally have larger laboratories to sustain. Even the occasional rejection of a large budget proposal can represent a significant negative kick for the productivity of their labs. Indeed, the investment in large blocks of time to "keep the lab going" leads some of these eminent scientists to modify their future research aspirations and overall career goals. Finally, after receiving a major award, some scientists change specialties or fields of inquiry.[29] When this happens, we view the manuscript completion rate for these transfer scientists as roughly equivalent to a new Ph.D. and with the same influence of negative reactions—if they occur—on their productivity.[30]

LIMITED DIFFERENCES: SOURCES OF DISPARITY BETWEEN GROUPS

The formulation of the evolutionary dynamics of science careers in the previous section makes no distinction, in principle, between different subpopulations—e.g., men vs. women scientists. Indeed, within each of these groups, the full range of qualitative principles listed as generic for the generation of productivity and kick-reaction histories is operative. Disparities between men and women are introduced as small (or limited) differences in probabilities associated with kick-reaction pairs for a small subset of the events in Table 13.1. In particular we assume that:

(*i*) For funding decision—event E_8—

$$\mathrm{Prob}_{[\mathrm{women}]}\,((k^-,r^-)\text{ on }E_8\,|\,\text{past history}) > \mathrm{Prob}_{[\mathrm{men}]}\,((k^-,r^-)\text{ on }E_8\,|\,\text{past history}) \quad (5)$$

Thus, given identical histories,[31] women tend to have negative reactions to grant rejections more often than men. Correlatively

$$\text{Prob}_{[\text{women}]}\,((k^-,r^+) \text{ on } E_8 \mid \text{past history}) < \text{Prob}_{[\text{men}]}\,((k^-,r^+) \text{ on } E_8 \mid \text{past history}) \qquad (6)$$

(ii)
$$\text{Prob}_{[\text{women}]}\,(k^- \text{ on } E_2 \mid \text{past history in early events module}) > \text{Prob}_{[\text{men}]}\,(k^- \text{ on } E_2 \mid \text{past history in early events module}) \qquad (7)$$

This inequality is motivated by the fact that a small proportion of the outstanding scientists refuse to accept women as their students, as noted above, thereby limiting—by a small amount—advantageous post-doctoral positions and subsequent support groups recommending them for both minor and major awards.

(iii)
$$\text{Prob}_{[\text{women}]}\,((k^-,r^-) \text{ on } E_6 = \text{birth of a child} \mid \text{past history}) > \text{Prob}_{[\text{men}]}\,((k^-,r^-) \text{ on } E_6 \mid \text{past history}) \qquad (8)$$

(iv)
$$\text{Prob}_{[\text{women}]}\,((k^-,r^-) \text{ on } E_{10} = \text{tenure decision} \mid \text{past history}) > \text{Prob}_{[\text{men}]}\,((k^-,r^-) \text{ on } E_{10} \mid \text{past history}) \qquad (9)$$

(v)
$$\text{Prob}_{[\text{women}]}\,((k^-,r^-) \text{ on } E_{15} = \text{critical reception of paper prior to publication} \mid \text{past history}) > \text{Prob}_{[\text{men}]}\,((k^-,r^-) \text{ on } E_{15} \mid \text{past history}) \qquad (10)$$

Correlatively

$$\text{Prob}_{[\text{women}]}\,((k^-,r^+) \text{ on } E_{15} \mid \text{past history}) < \text{Prob}_{[\text{men}]}\,((k^-,r^+) \text{ on } E_{15} \mid \text{past history}) \qquad (11)$$

Inequalities *(i)* and *(v)* imply that women tend to get more discouraged by negative decisions on grant applications and critical commentary about their work than men.[32] Although this is not universally the case, the consequence of the negative reactions is to slow down the manuscript completion rate by a small amount. Over a period of 7–10 years this can result in major disparities in productivity between otherwise indistinguishable men and women scientists. Thus the full set of inequalities, *(i)–(v)*, coupled to the conditional probability specifications on p. 294 constitute the basic formalism of the theory of limited differences, as applied to science careers. Quantitative implementation of this formalism with a range of functional forms for the conditional probabilities based on past histories requires a *family* of microsimulation models, which will be reported on in detail in a later publication. The point of embedding this general evolutionary theory of science careers in a *family* of models is that the manuscript completion and publication histories are relatively insensitive to a diversity of perturbations in kick-reaction histories. This is a form of structural stability of science careers; that is, most small variations in the details of the kick-reaction histories do not lead to qualitatively different career paths.

Examples of Individual Histories and Their Interpretation

In order to clarify the character of microsimulation implementations of the theory of limited differences, we construct three hypothetical examples of science careers: one for a prolific and eminent male scientist; a second for a woman who is less prolific but eminent; and a third for a less productive and noneminent woman scientist who might have been more prolific but for her action-reaction experiences. These hypotheticals represent only three of a myriad of possible careers and are intended to clarify the three interrelated sequences of kicks and reactions, completed manuscripts, and publications which develop over a career. They are portrayed schematically as shown in Figure 13.3. The cumulative effect of the early kick-reaction pairs heavily influences the early and mid-career manuscript completion rate, based on the events E_1 (acceptance into Ph.D. institution), E_2 (acceptance of Ph.D. sponsorship), E_3 (first post-Ph.D. job), and, if they occur prior to E_3, decision on first manuscript submitted for publication (E_4), E_5 (entry into first marriage or cohabitation), or E_6 (birth of a child).

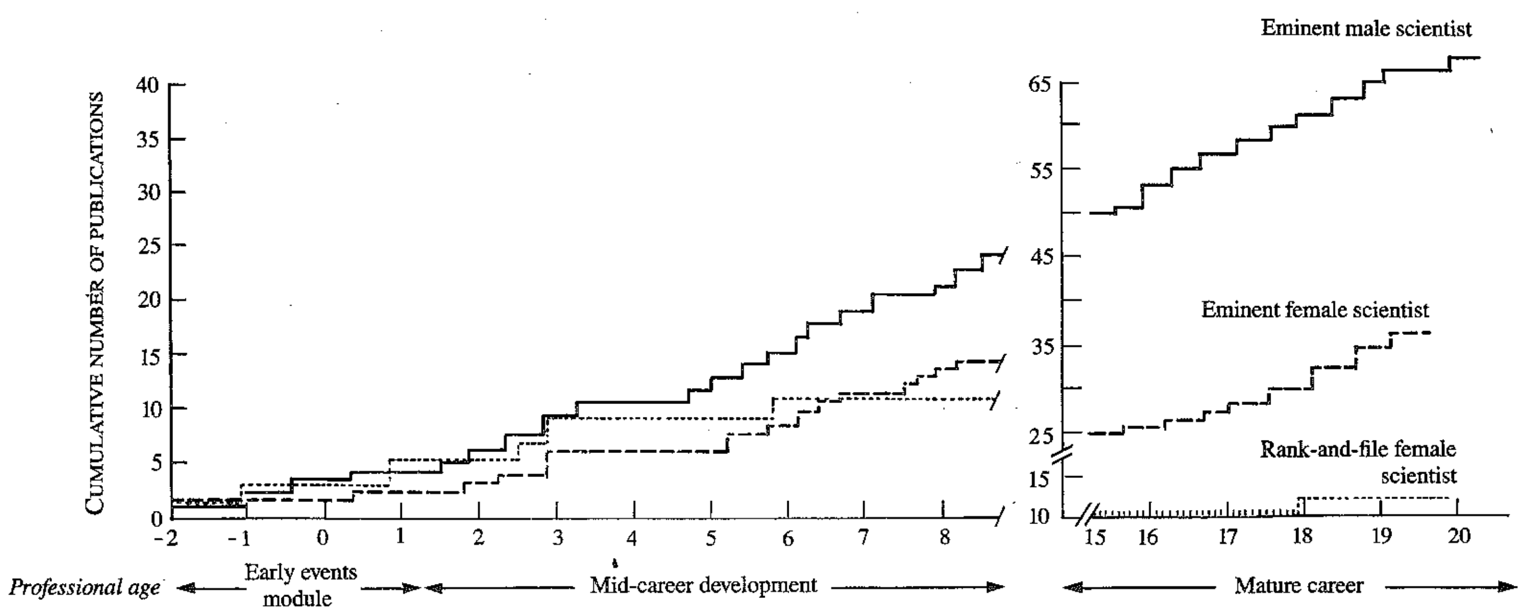
The case history for the eminent male scientist begins by noting that his personal background and academic record prior to the Ph.D. produced a sense of great self-confidence in his scientific ability. His reaction system was geared toward success; he had high expectations for achievement. And indeed, his first three events are all positive, experiencing (k^+, r^+) pairs in terms of admission to the top Ph.D. department of his choice, acceptance by a first-class sponsor, and receipt of a distinguished job upon completion of his degree. These kick-reaction pairs serve as a major cumulative influence on his rate of manuscript completion. This produces a strong incentive to succeed in competition with other scientists for important discoveries. The cumulated positive reaction intensities in the "early events module" determine the initial manuscript completion rate immediately following the first post-Ph.D. job. This rate can, of course, be modified by later events. These early positive reactions then interact with the positive outcome and reaction of the scientist to having his first grant application ($E_8^{(1)}$) funded. This further increases the probability of high rates of manuscript completion and submission for publication.

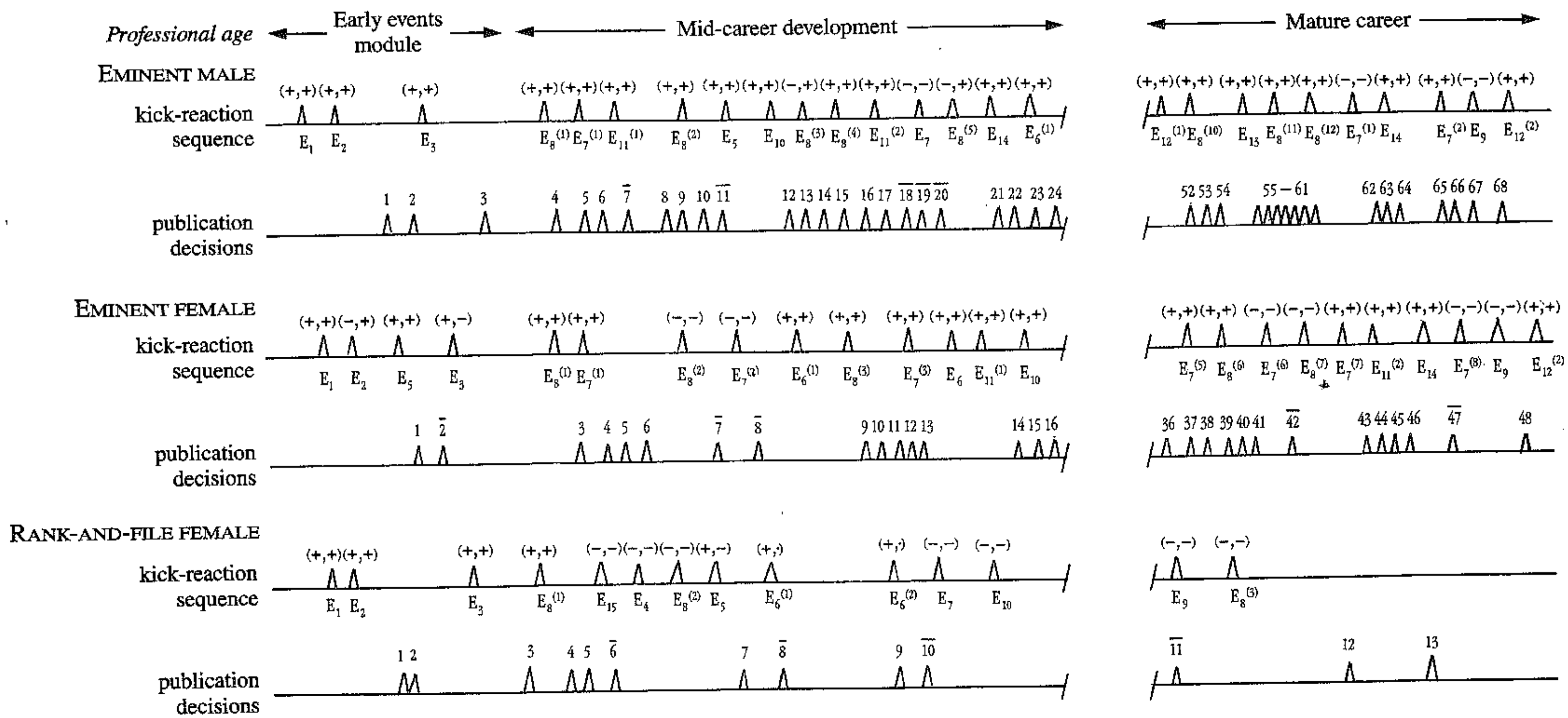
K E Y

(,) kick-reaction pair--e.g, (+,-) means positive kick, negative reaction

$E_i^{(a)}$ means j^{th} occurrence of i^{th} event

$\overset{m}{\Lambda}\ \overset{\bar{n}}{\Lambda}$ submitted manuscript m accepted for publication; manuscript n rejected





13.3 Simulation of manuscript completion and kick-reaction histories.

The early events experienced by the eminent female scientist are similar to her male counterpart's (see Case 2, Figure 13.3). Her early educational achievements produced high personal expectations and lofty aspirations. She is confident about her aptitude for science but experiences some cross-pressure because she wants to mix a marriage and family life with a scientific career and has been led to believe that this may be risky for a woman with lofty scientific aspirations. Nonetheless, her confidence abounds and her reaction system leads her to be strongly motivated to succeed in science. She works in the same field as the eminent male scientist that we have just discussed. The female scientist experiences a (k^+,r^+) pair for acceptance into a top Ph.D. institution. Immediately following graduate school, she marries a highly eminent scientist in her own field. In this case marriage represents an initial positive kick. She has increased opportunities to enter the network of leading researchers in her field—far better opportunities than those open to most other men and women of her professional age. These positive kick-reaction pairs represent strong incentives for her to begin publishing, which she does successfully. But she is married to a man whose career is firmly rooted in a very restricted geographical location. His job is not in close proximity to the outstanding academic or government research laboratories that have positions available that would best facilitate her career. The effect of what at the time appears to be a positive kick—i.e., entry into first marriage—is delayed until completion of the Ph.D., when it interacts with the woman being offered a position at a distinguished institution and her reluctantly declining the offer as a result of the geographic immobility of her husband. This discouragement, which is associated with the pair (k^+,r^-) for E_3, can serve to lower initially the aspirations of someone who might otherwise have been very highly motivated and skilled and with full capability of being one of the very best in her field. This negative reaction is interpreted as setting a lower initial manuscript completion rate than exists for the male scientist in Case 1, who did not experience a dramatic negative reaction in the early events phase of his career.

Observe also that the female scientist experiences a negative kick from being turned down by her first-choice Ph.D. sponsor $[E_2(k^-,r^+)]$, who refuses to sponsor women, believing that they are poor risks who are apt to drop out of science to get married and raise children. For this particular woman the discrimination engenders a further fight to show the first-choice potential sponsor the error of his ways. For many women, however, this kind of negative kick can lead either to lower aspirations or, subsequently, to lower probability of finding a first job in a top post-doctoral position due to poorer training or lack of national influence of her sponsor. It also leads to a slight advantage for male scientists in the early career stage and later in regulating the probabilities of receipt of both major and minor awards.[33]

Returning to Figure 13.3, observe that following E_3 there is very little difference in the manuscript completion and publication histories for male and female scientists, except that the completion rate for the male (driven by the stronger initial cumulated positive reactions) dominates that of the female scientist. In addition, negative kicks from a few grant rejections do not lead to negative reactions by the male scientist, whereas they do lead to such reactions, with a slight accompanying reduction in the manuscript completion rate, for the female scientist. Recall that we are treating (k^-, r^-) pairs on grant decisions as proportionately slightly more frequent among women than men, assuming a priori that a slightly higher proportion of women are somewhat more vulnerable than men to intense negative reactions from grant rejections, leading thereby to a slight reduction in their relative productivity.[34]

For the woman, the early large negative reaction of not accepting an optimal first job (E_3) and mild discouragement from the grant rejection (E_8) leads to a slower rate of accumulation of publications by the female relative to the male scientist working in the same field. The birth of a child (E_6) before the tenure decision does not produce a negative kick for the woman's productivity, but it does take her away from her department and colleagues and contributes to a delay in the decision on her tenure.[35] The woman scientist receives tenure (E_{10}), but somewhat later than her male counterpart—after roughly 15 completed manuscripts, compared with 11 for the man. Thus, the intensity and set of consequences of the positive reaction to the tenure decision is less than it was for the man. In terms of publication histories, this also reduces for some time her ability to attract the best graduate and post-doctoral students and to build the size of her laboratory. By the time the male receives his first major award ($E_{12}^{(1)}$)some 15 years after the Ph.D., the ratio of female to male publications is 30/52—or roughly .58. The accumulating publication disparity exhibited in these caricatures is a common but not universal feature of male–female differences among very eminent scientists. Each negative reaction for the woman on a few events contributes a small amount toward slowing down the manuscript completion rate—as it would for a man as well. Over a major portion of a career, say 20 years or so, this gives rise to a substantial disparity in lifetime productivity as measured by publication counts.[36]

For analytic purposes, the third phase of the career development process is assumed to begin after a scientist receives at least one major award. At this point a branching takes place. For the vast majority who continue to do scientific research, many begin to manage larger, quality laboratories. They obtain greater resources, their production of manuscripts increases dramatically, although their own relations to production often change. Thus, becoming the director of an excellent lab at a distinguished institution relatively early in a career often leads to substantial increases in output. Note that in our hypothetical examples, the eminent male scientist is made director of such a laboratory almost immediately after being honored with a major award; the woman does not receive this positive kick at all—although she might well have expected it. We assume that men are more apt than women to assume such directorships—and comparatively early on in the career.[37] This is viewed, in the present formulation, as a consequence of the slightly higher probability of outstanding male scientists having Ph.D. or post-doctoral sponsors who are particularly influential and who facilitate the visibility of their intellectual progeny and sponsor them for minor and major awards at early ages. Thus, a virtually undetectable "limited difference" in the early events module can have major consequences in the later career stage.

The second woman (see Case 3, Figure 13.3) was also labeled as an exceptionally able youngster, although she retained a sense that her success was more a result of hard work than ability. Working in astrophysics, she attends a distinguished graduate school, holds a major pre-doctoral fellowship, and receives excellent training from her first-choice sponsor (E_2). She publishes papers with her sponsor before receiving the Ph.D., accepts a first job offer at the most distinguished department in the country (E_3), and finds herself among the brightest and most dedicated young scientists she has ever encountered. Competition is fierce in the fast lane in which she is traveling.

As an assistant professor, she is the sole author of two papers in prestigious journals and receives two years of support from the National Science Foundation (NSF) for her research. Her sense of competence increases, but a paper she thought offered a particularly novel solution to a long-established problem is received poorly by some of her distinguished colleagues who are important reference individuals for her (E_{15}) and is rejected by a major journal (E_4). She begins to question her originality compared to the other bright and seemingly indefatigable assistant professors in her department. This slight loss of self-confidence is exacerbated when a research proposal of hers is rejected ($E_8^{(2)}$). Her motivation to complete several manuscripts and submit manuscripts and grants for peer review is dampened, leading to delays in her submissions.

Her marriage to a nonscientist (E_5) and the subsequent birth of two children ($E_6^{(1,2)}$) does not result in loss of time in the laboratory, but it does mark the end of all her "discretionary" time. However, the termination of her grant and the rejection of a second manuscript reduces her motivation and her career aspirations and leads her to question whether she can maintain the pace of research required by her department. The final blow to her aspirations and motivations is her denial of tenure (E_{10}) by her distinguished department. Not satisfied with being simply run-of-the-mill, she cuts back significantly on the pace of her research—reducing still further the probabilities that she will continue to be a prolific scientist.

This scientist was headed for membership in the productive elite but experienced a set of slight negative kicks, which accumulated over time and interacted with her self-doubt about her ability to compete with the best young minds in her field. The several paper and grant rejections sting her; the denial of tenure is an intense kick. Together these events and the concomitant reactions lead to a longer time between completion and submission of manuscripts. She slowly moves out of the fast lane and never receives a major award. It is important to emphasize that precisely the same event history could be constructed for men scientists. The inequalities detailed above imply that the probability of the sequence of negative kicks and reactions are more apt to be part of the career histories of women than of men scientists.

Competition

I was competitive beyond the run of younger mathematicians, and I knew equally that this was not a very pretty attitude. However, it was not an attitude which I was free to assume or reject. I was quite aware that I was an out among ins and I would get no shred of recognition that I did not force. (Wiener 1956: 87)

The formulations in this chapter may be viewed in many respects as a theory about the response of the community of scientists to an unstated driving force: competition. The social system of science is driven by competition in at least two forms. There is competition for ideas and hence priority in discovery and competition for the funds which are, in many instances, essential for the pursuit of particular lines of inquiry.[38] In the era of "little science," competition for ideas was the dominant form of this phenomenon. However, with the very large economic costs of resources for doing such things as high energy physics via particle accelerators, astrophysics via satellite observations, or climatology via deep sea sediment cores, competition for ideas is now augmented by and thoroughly intertwined with competition for funds.[39] This two-sided competition is particularly acute among the stratum of prolific, highly productive research scientists located at the major scientific institutions—those few who account for such a large proportion of all scientific discoveries.

Biographical reports and sociological studies ranging from large-scale surveys to studies of individual laboratories testify to the centrality of competition in the lives of scientists.[40] There are strong interactions between the action (kick)-reaction system as delineated in this chapter and competition processes, particularly due to the scarcity of resources for pursuing many types of scientific inquiry. Scientists' perceptions of the peer review systems of the National Institute of Health (NIH) and the National Science Foundation (NSF) bring to life the interrelationship between the action (kick)-reaction system, competition, and scarcity.[41] Scientists' productivity is linked directly to keeping the laboratory operating at a high pitch, and it is becoming increasingly difficult and time consuming to obtain the necessary support.

Competition for ideas and priority in discovery exists for some problems, especially in the upper echelons of any scientific discipline, with the competing parties having nearly complete knowledge of what their competitors are doing. The quintessential example of this is, of course, the race for determination of the structure of DNA by the Watson–Crick and Pauling labs.[42] The intense transfer of information via frequent conferences, private laboratory visits, and even telephone conversations between competitors and / or their close collaborators plays a major role in structuring research agendas and in regulating the duration of time between experiment completion, manuscript submission, and publication.

The increasing awareness of the centrality of competition processes as a driving force in science has, unfortunately, not been accompanied by the extensive empirical research which is required to document the fine-grained relationships between competition and the events presented in Table 13.1. Empirical research to date lacks specificity on the focus of competition, its types and intensities; it also lacks detail on the role played by reference groups and social networks in producing and maintaining competition. Furthermore, the fragmentary evidence currently at hand indicates that there is substantial heterogeneity across subspecialties in forms of competition. Because of the sketchy nature of the available evidence about competition in science and because of the complexity of the phenomenon itself, we have not attempted to formalize competition processes or their precise interrelationship to the action (kick)-reaction system already described. We view clarification of the details of competition processes in science as a topic of major importance for future elaboration of the theory of limited differences. In the present discussion, competition remains implicit in the action (kick)-reaction formulation.

Conclusions and Discussion

The theory of limited differences proposes an explanation for social patterns of group differences. It offers a theoretical explanation for dynamic patterns of increased differentiation, increased attenuation, or social stability in the relative standing of the groups over time. At a micro level of analyzing individual histories, it examines dynamic interactions in which small, limited differences in reactions lead to large changes in individual career histories over extended periods of time.

The theory avoids reliance on "causal" models that emphasize the action of one or two variables as determining agents, or on a battery of correlates where no interrelationships have been either theoretically described or empirically demonstrated. The theory allows us to specify precisely the interrelationships between concrete events in the histories of individuals, a set of reactions to these experiences, and the short- and longer-term consequences on processes of differentiation in scientific productivity.

To test the theory, a program of research focusing on conceptual and methodological problems is required. Included in the portfolio of problems are: determining the relationship between actions and reactions (and the adequate fine-grained measurement of the sequence of events); determining the relative intensities of a variety of actions and reactions that influence outcome variables; understanding the influence of the "anticipation" of events on the selectivity process; examining empirically the nature of time dependencies between events and their consequences; examining how action (kick)-reaction pairs are influenced by organizational and network structures; determining the precise relationship between micro-level outcomes and macro-level, system outcomes; and determining precisely the relationships between structural analysis, social psychology, and culture.

The simple aggregate trends, exhibited in Figure 13.1, indicating the increasing disparity ("fanning out") between cumulative publication counts of men and women scientists, can be modeled by exceedingly simple mathematical representations. Polynomial growth curves (Foulkes and Davis 1981; Ware and Wu 1981) with gender-specific parameters and Polya urn schemes (Feller 1968) with gender-specific selection probabilities are two of the most obvious possibilities. Unfortunately, simplistic models of this kind do not incorporate the fine-grained behavioral assumptions necessary to provide an *explanation* of the patterns in Figure 13.1 in terms of more primitive psychological and sociological constructs. The theory of limited differences is one proposed explanation. It is highly *non*-parsimonious in terms of models which can account for these patterns, but, on the other hand, it is rooted in fundamental behavioral processes. Finally, it suggests that criteria in addition to an ability to reproduce the patterns in Figure 13.1 should form the basis for assessments of whether or not empirical data can support the theory.

A minimum restriction is that we should require data on kick-reaction pairs associated with E_2, E_6, E_8, E_{10}, and E_{15} to support the inequalities (5)–(11) characterizing the sources of disparity between men and women scientists. It is important to emphasize that while gender differences in publication counts are not detectable over short time intervals, gender differences in the frequency of occurrence of kick-reaction pairs—i.e., for events E_2, E_6, E_8, E_{10}, and E_{15}—conditional on full or partial past histories should be ascertainable.[43] In addition, there should be *no* discernable gender differences in the frequency of occurrence of kick-reaction pairs for events other than those indicated above.

Having imposed this set of requirements on empirical evidence needed to support the limited differences theory, it is essential to address some basic—and as yet unanswered—questions about measurement processes. If we try to recover scientists' career histories from longitudinal surveys, then we need a defensible basis for structuring questions that will yield trustworthy responses for the nine types of kick-reaction pairs delineated herein. For events such as those in Table 13.1, we must know how far back in time retrospective questions can be posed in a formal survey so that kick-reaction pairs can be defensibly recovered.

More basic than the above questions is the issue of just what one means by an accurate report of a reaction—i.e., whether r^+, $r^\cdot$, r^-. There is no independent way to assess, for a given person, the accuracy of a reaction report *and* a statement of its impact on motivation to complete manuscripts. While we can observe the consequences for manuscript completions of the kicks, k^-, k^+, which are often readily ascertained regardless of the elicited reaction, defensible and relatively objective assessments of reactions is probably not achievable by standard survey instruments. The closest that one is likely to get to a "gold standard" for reactions is participant observation studies in which sociologists are members of a laboratory—as at Rockefeller University, a Hughes Institute, Fermi Lab, or the Stanford Linear Accelerator Center—where it is possible to observe (unobtrusively) in detail, and continuously over time, the behavior of scientists following receipt of kicks. The observed behaviors would then lead to characterizations and designations of r^+, $r^\cdot$, r^- by the observer; and this would represent the standard for comparison against scientist-elicited responses. There are already some participant observation studies of this kind (see, among others, Latour and Woolgar 1979; Knorr-Cetina 1981; Gilbert and Mulkay

1984) not conducted with an eye toward kick-reaction measurement, but certainly allowing for classification of behaviors and assignment of reaction types.[44]

Many more participant observation studies must be carried out if there is to be deep understanding of the psychological and social processes that are the basis for science careers. Furthermore, there is no substitute for this kind of study if there is to be a clear understanding of the competition processes which drive science careers. An unobtrusive observer, witnessing laboratory discussions of what competitors are doing and listening to the debate and rationale for problem choices, is a central feature of the measurement processes which can either support or refute the limited differences theory. An additional strategy for ascertaining reactions would be to have temporally specific interviews with both the scientist whose reactions are being measured and the fellow scientists who are themselves "witnesses" of the reactions. Through intensive questioning of role partners, it may be possible to increase the reliability of the participant observer's judgment of reactions to specific kicks.

Fine-grained nuances must be ascertained if kick-reaction designations are to be trusted; and it may be that standardized questionnaire surveys will be of limited value relative to within-laboratory participant observation studies. In particular, we expect that in the course of developing tests of the limited differences explanation of science careers, it will be necessary to develop further and elaborate on the structuring and analysis of vignettes (Rossi 1979). We envision the vignettes being prepared by the on-site observers in laboratories.

Shifting from measurement issues back to limited differences theory per se, there is another aspect of choice behavior by scientists that is not reflected in the theoretical formulation presented in this chapter but that deserves precise formalization as part of a research agenda for the future. The missing ingredient is the notion of a scientist's anticipation of future kicks of either positive or negative type and the influence of such perceptions on current motivation, hence on his (her) manuscript completion rate. Evidence from focused interviews (Cole and Zuckerman 1987) suggests that the perceptions about future events which influence productivity are unions of events and their associated kicks, rather than the precisely timed single events and kick-reaction pairs which govern the career history constructions described in this chapter. Whether a scientist perceives future positive or negative kicks on an event such as a grant decision, or candidacy for awards such as Guggenheim fellowships, or election to a professional society, depends on *both* past personal kick-reaction history *and* a consideration of what the competition is doing scientifically and receiving in the way of rewards. It will also be governed by his (her) perceptions of the composition of the judges who will act on his or her proposal or application (Cole 1987). Assessments of anticipation of future events and the influence of these perceptions on a scientist's productivity will almost certainly require participant observation studies of the kind mentioned above. A full delineation of anticipatory processes and their interaction with the kick-reaction paradigm and limited differences explanation for productivity differentials between men and women is, in our opinion, a major task for future theoretical and empirical development. The present essay should be viewed as a first step in an extensive program aimed at a much deeper understanding of the characteristics of scientific careers.

13. A Theory of Limited Differences

1. A formal presentation of the general theory is currently in preparation.
2. The male–female difference exists within every productivity stratum, for example, when career publication totals are divided into quartiles or total publications in 12–15 years following the Ph.D., or longer periods of time (see Figure 13.1).
3. On strategic research sites, see Merton 1987.
4. Throughout this paper "scientific productivity" will refer to the number of scientific articles that are published within specific units of time. Whether we discuss total counts or papers per year, we refer to the number of papers published. There is a large literature on problems in measuring scientific productivity and its relationship to both the quality of scientific work and its impact. See among many others Cole and Cole (1973), Cole (1979), Gaston (1973, 1978), Allison and Stewart (1974), Long (1978), Long and McGinnis (1981), Reskin (1977, 1978a, 1979), Andrews (1979), Allison (1980), and for recent groups of Ph.D.s, Cole and Zuckerman (1984). Suffice to say, publication counts are strongly correlated with impact as measured by peer appraisals and by citations, as well as with the prestige of honorific awards.
5. See Price (1963). Subsequent studies demonstrated that this pattern obtains in every scientific discipline studied, and for the United States and all other nations whose scientific output have been examined. While we have charted these patterns well, there have been no successful attempts to explain them.
6. Cole (1979) reports data on the relationship between sex status and publications for matched samples of male and female Ph.D.s, who received their degrees in the same year and from the same science department in 1922, 1932, 1942, 1952, 1957–58. The association is illustrated for each of these distinct cohorts in Figure 13.1.
7. Scientists were drawn from six fields: astronomy, biochemistry, chemistry, earth sciences, mathematics, and physics. Pairs of scientists were matched in the sense that they were selected from the same departments in the same years. Analysis was performed both on the aggregates of 263 pairs and on individual pairs. The results were much the same regardless of the type of comparison.
8. While patterns of citations to published science by men and women look much the same as the productivity patterns, evidence suggests that women scientists publish articles that receive just as many citations per article as do men. Thus, the differential in citations appears to result from the greater total output of the men.
9. For each of the five pictures shown in Figure 13.1, the random samples of scientists were matched by year of Ph.D., field, and department of Ph.D. Where possible, men and women were matched by specialty at the time of receiving their degree. Publication data were obtained from abstracts. For a complete description of these samples see J. R. Cole (1979).
10. For descriptions of the diverse set of samples that we have collected data on, see Cole and Cole (1973, 1976, 1985); Cole, Rubin and Cole (1978); Cole, Cole and Simon (1981); Cole, Cole, and the Committee on Science and Public Policy (1981); Cole (1975); Cole (1979); Cole, Cole and Dietrich (1978); Zuckerman and Cole (1975); Zuckerman and Merton (1971a, 1971b); Zuckerman (1970, 1977).
11. This observation was made repeatedly in recent extended interviews with 123 men and women of science conducted by Harriet Zuckerman and J. R. Cole.
12. Plainly, there are many other outcome variables in science, such as appointments to various positions and peer recognition. In this chapter we focus exclusively on the research role and on those who are the major contributors (operationalized by producers of x or more papers within y years of receiving the Ph.D.) to the development of science through publication. This is a small percentage of Ph.D. recipients in science and is nearly invariant across Ph.D. cohorts from 1920 to the present. There are, at present, no obvious early screening criteria to ascertain (at Ph.D. completion) who will fall into this group.
13. The term "kick" is drawn from the physical science literature and is used here in a completely neutral way since it refers to a positive or negative event or perturbation. Kicks are experienced by men and women, and no invidious comparison is intended by the use of this term.
14. Condition (V) implies that every detail of past history will not influence future events in a unique and idiosyncratic fashion. The same outcome history can arise in a multiplicity of ways.
15. The theory of limited differences calls forth a series of interesting metaphors drawn from the biological and physical sciences. We need

only look to Darwin's *The Origin of Species* (1859) for a clear articulation of the effects of small cumulating differences, which may not even be distinguishable for substantial periods of time, becoming the basis for highly notable variations in species. In his chapter on natural selection, or the survival of the fittest, Darwin has many references to the influence of small differences over time. Consider only one:

> during the modification of the descendants of any one species, and during the incessant struggle of all species to increase in numbers, the more diversified the descendants become, the better will be their chance of success in the battle for life. Thus the small differences distinguishing varieties of the same species, steadily tend to increase, till they equal the greater differences between species of the same genus, or even of distinct genera.

E. O. Wilson's concept of "multiplier effects" also recognizes how small differences can interact with the environment to produce larger effects:

> A small evolutionary change in the behavior pattern of individuals can be amplified into a major social effect by the expanding upward distribution of the effect into multiple facets of social life. . . . Multiplier effects can speed social evolution still more when an individual's behavior is strongly influenced by the particularities of its social experience. (Wilson 1975: 11–13)

Finally, we find parallels to the concept of an action-reaction system in the experimental embryologist C. H. Waddington's concept of "competence" developed almost 50 years ago. In his discussion of competence, Waddington (1940) notes:

> In the first place, it is a state of instability, since it involves a readiness either to react to an organizer and follow a certain developmental path, or not to react and to develop in some other way . . . one can compare a piece of developing tissue to a ball running down a system of valleys which branches downwards, like a delta. . . . The tissue, like the ball . . . must move downhill, but at some points there are two downhill paths open to it. At such branching points, it may sometimes require a definite external stimulus, such as evocator substance, to push the tissue in to one of the developmental paths; in such a case, competences which occur later along this path will only be developed if the evocator has acted. In other cases, a certain path may be followed merely because an evocator has failed to be present, and then the subsequent competences may appear to develop autonomously." (p. 45)

The theory of limited differences calls forth a series of additional metaphors drawn from other scientific disciplines. The image of the controlled chain reaction is one such metaphor. There an initial action can of course balloon quickly into a large difference if many "kicks" for one group line up positively and all of the kicks for the other group are negative. In such a limiting case, enormous differences between men and women would occur as their careers unfold. But the qualitative data suggest that men *and* women experience both positive *and* negative kicks that we hypothesize affect scientific productivity and career advancements. In fact, the chain reaction which might lead from small initial differences to enormous disparities is modulated by a set of competing and conflicting positive and negative forces. These are metaphorically the barium rods which slow down or even halt the initial chain reaction. Consider another metaphor. We place a big stone on top of a hill; we let it begin to roll down. Depending on tiny impulses it gets, it moves one way or another and will end up in a very different place at the bottom, depending on the smallest chance variations. Each small perturbation changes its trajectory for the future. And the longer the hill, the larger the possibility of spreading apart from the initial path. Still another metaphor is drawn from the kinetic theory of gases or fluids model. Here each scientist is viewed as a molecule. External events move the molecule in one direction or another. The path varies according to the number and types of pushes.

While these concepts help convey the image of actions and reactions as well as the concept of the long-term larger effects of initially small differences, in important respects each fails to capture a critical feature of the theory of limited differences. The fundamental distinction lies of course in "consciousness," that is, the ability of scientists to react to events in nonmechanistic ways that are not akin to reactions by either particles, molecules, or the biological systems described by Waddington or Wilson. Thus, these concepts drawn from biology are at best weak analogies to the distinctly socially structured action-reaction system developed here. Salome Waelsch brought Waddington's work to our attention and helped make us aware of the centrality of the reaction system for the theory of limited differences.

16. Here a truncated description is required. An in-depth critical appraisal of these earlier orientations will be published elsewhere.
17. There have been no agreed upon measures that predict scientific talent, imagination, or aptitude. IQ scores, at best a weak measure of scientific ability, have been found, first, to be uncorrelated with sex, as well as with publication counts and citations. Bayer and Folger (1966) found a correlation of .05 between IQ scores and citations to scientists' work (see also, Harmon 1963, 1965); Cole (1979) found a correlation of −.03 between publication counts and IQ for the first 13 years of the careers of men and women scientists receiving their Ph.D.s in 1957–58. Although men tend to have higher scores than women on the mathematical portion of the SAT and GRE, the explanation for this difference remains unclear. There is no evidence that after the groups are socially and self-selected into Ph.D. programs that this difference is reflected in subsequent performance.
18. For elaborations upon Merton's work, see, among others, Cole and Cole 1973: 237–247; Allison and Stewart 1974; Allison, Long and Kraus 1982; Zuckerman 1977; Cole 1979; Mittermeir and Knorr 1979; Zuckerman 1989.
19. In the first half of this century, the application of nepotism rules, of quotas on having members of certain religious groups, and of an unwillingness to have women working in certain laboratories represented discrimination that significantly influenced the scientific productivity and career histories of women and men who were adversely affected by these discriminatory practices.
20. Although these theoretical concepts have been used to explain sex differences in productivity, they are applied, almost invariably, as a fortiori or post factum interpretations of observed patterns. There has rarely been an attempt to test precisely these theoretical interpretations. Either data do not exist for direct tests of the theory, or the tests have been carried out with imprecise and often questionable "proxies" for key variables.
21. It is important to assert at the outset that the stochastic process formulation with strong memory effects and dependence among multiple variables developed herein represents a mathematical formalization of a very specific theory. Much of the modeling activity in the contemporary sociology literature is *not* of this character and is of an exploratory data analytic type where the goal is to assess which combination(s) of an a priori list of variables are the important influences on a given outcome variable(s). With this particular goal, standard regression modes with interaction terms including dynamic autoregressive models are the most prominent tools. This class of models, however, does not include a formalization of the limited differences theory. Indeed, the standard strategies for incorporating interactions among variables—i.e., as multiplicative terms—in regression models are too crude to represent the more subtle nonlinearities in the limited differences theory.
22. Zuckerman and Merton, *Minerva*, 1971b. The probability of a manuscript being published is largely a function of the effort by the scientist to see the paper through to publication. In fields and specialties with high specific journal rejection rates, the decision to resubmit an article either to the same journal or to a different one almost invariably leads to some form of publication. This may not always be in the journal of first choice, but it will result in publication. Zuckerman and Merton show in their study of *The Physical Review* that eminent scientists not only published more than run-of-the-mill scientists but submitted about twice as many manuscripts for publication over a nine year period: 4.1 for those of the highest rank; 3.5 for the intermediaries; and 2.0 for physicists of the third rank. And the most prolific physicists submitted papers to *The Physical Review* at a rate 12 times that of the rank-and-file. (In Merton 1973: 479.)
23. A full empirical refinement of the publication process outlined here is an important agenda item for future research.
24. A more fine-grained classification involving intensities of kicks and reactions is both possible and meaningful; however, the coarse categories—positive, neutral, and negative—will be utilized to simplify the theoretical formulation herein and focus on the principal concepts.
25. The types of actions and reactions and their sequencing will vary from one historical period to another. Figure 13.1 illustrates an historical pattern of sex differences in scientific publications dating back to the 1930s. Although the aggregate level pattern persists, this does not mean, of course, that the cultural, social structural, or psychological factors that produce the patterns have remained constant. On the contrary, historical evidence suggests that the structure of action (kick)-reaction pairs, and in particular, their intensities, have changed in the past 50 years. The historical changes will be captured in the

transformation of the kick-reaction pairs and, indeed, the replacement of some by others.

26. The analytic division of science careers into three phases is appropriate because there is evidence in the sociology of science literature that early events are critical in shaping subsequent probabilities for publication and rewards. The analytic phasing discussed here may not be appropriate when considering other dynamic processes of differentiation and subsequent fanning out or attenuation of the differences.
27. In a study of physics awards, only one third of scientists report any awards; the most prestigious awards were monopolized by a small subset of scientists (see Cole 1969; Cole and Cole 1973; Zuckerman 1977).
28. Zuckerman 1977, chap. 6.
29. The possible examples here are numerous. To cite only one, Donald A. Glaser, the inventor of the bubble chamber, shifted from physics to biology after receiving the Nobel Prize.
30. This assumption needs testing, since undoubtedly the prestige of the Nobel Prize and other major awards cuts across fields and may in fact increase the initial probabilities that manuscripts produced by major award winners in the new field will meet with a more positive reception than those produced by recent Ph.D.s in the field.
31. In all inequalities in this section, the past histories for the men and women are identical in the conditioning events. Thus comparable histories still yield gender differentiated responses.
32. Empirical evidence supporting these limited differences comes from extensive focused interviews with eminent and rank-and-file men and women scientists conducted by Jonathan R. Cole and Harriet Zuckerman. It should be emphasized that many men and women react in precisely the same way to negative kicks. Indeed, the distributions probably show more similarity than difference; the differences in probabilities are not large.
33. This example suggests that discrimination is one of the fundamental sources for negative kicks in the sequence of action-reaction pairs. Plainly, discrimination need not be rampant for it to have a notable cumulative effect on the publication probability of a subset of women or men who suffer from the initial negative kick and from the negative reactions in terms of motivation and future aspirations.
34. There is actually some empirical support for this assumption. In terms of subsequent publication rate, men scientists are affected more positively by peer recognition in the form of citations than are women. Conversely, women are more adversely affected than men by a lack of peer recognition. In other terms, positive reinforcement has less of a positive effect on productivity for women than for men; negative reinforcement has a greater negative effect for women than men. Cf. Cole and Zuckerman (1985).
35. There is a growing literature that indicates that marriage and family obligations affect women's careers, but not in terms of published productivity (see Cole 1979; Cole and Zuckerman 1987).
36. The empirical fact is that some eminent women receive more positive and fewer negative kicks than some eminent men. For this subset, the summary of kick-reactions would indicate that these women tend to produce more manuscripts than the men. It is by no means invariably the case that the careers of women show more negative kicks and negative reactions than men. In general, however, this has tended to be the case, and we hypothesize that the cumulation of these micro-level limited differences explain the macro-level disparity in publications.
37. There is, of course, a subset of eminent scientists who accept offers as administrators and public servants after achieving lofty recognition. Their publication rate is usually drastically reduced and, in some instances, virtually eliminated. Thus it is necessary in our formal specifications of career development to allow for the termination of a publication history following the receipt of one or more major awards.
38. For an extended discussion of priority disputes in science, see Merton 1957.
39. Cole and Cole 1981, 1985; Cole, Cole and Dietrich 1978; Cole, Cole and Simon 1981.
40. Merton 1957; Hagstrom 1965; Latour and Woolgar 1979; Knorr-Cetina 1981.
41. The contemporary situation is placed in bold relief by the eminent biochemist Arthur B. Pardee:

> At the heart of current problems [in maintaining high scientific quality and productivity] are the difficulties and uncertainties every scientist faces in obtaining research funds. . . . A scientist perceives now that he has a small probability of getting a grant funded. He cannot afford to be without funds for a year or more if his application fails, because continuity is essential for progress and to retain highly trained, key personnel. So he writes [multiple] proposals in the hope that one of them will be lucky. . . . Fund raising rather than re-

> search becomes his major preoccupation. . . . Talents of fine scientists are a rare commodity; wasting them is a very costly proposition. . . . A less evident but also highly important consequence is the diminution of scientists' self-confidence and morale. Rejections by the funding system of one's best ideas are extremely discouraging. We will see scientists in increasing numbers decide that they are in a rat race; they will slow down or get out. Some of the best unfortunately will be among them. (As quoted in Cole and Cole 1985, p. 28).

Similar opinions were voiced by many of the productive men and women scientists that were interviewed over the past four years.

42. Many other less well-known examples could be cited; for example, the competition between the labs of Andrew Schally and Roger Guillemin to identify the structure of TRF(H), Thyrotropin Releasing Factor (Hormone). See Latour and Woolgar 1979.

43. Verifying or refuting this claim is a major research task for the future. The supporting evidence to date is primarily from focused interviews which were not designed a priori to assess these points (see Zuckerman and Cole 1987). A content analysis of the interviews, and 20 years of study of the scientific community, often with various forms of quantitative data, suggested inequalities (5)–(11) and provided informal support for the limited differences explanation of Figure 13.1

44. Of course, even participant observation studies have the weakness of imputation, that is, the observer imputing reactions that are translated through his or her own set of constructs.

13. A Theory of Limited Differences

Allison, P. D. 1980. "Inequality and Scientific Productivity." *Social Studies of Science* 10: 163–179.

Allison, P. D. and J. A. Stewart. 1974. "Productivity Differences Among Scientists: Evidence for Accumulative Advantage." *American Sociological Review* 39: 596–606.

Allison, P. D., J. S. Long, and T. Kraus. 1982. "Cumulative Advantage and Inequality in Science." *American Sociological Review* 47: 615–625.

Andrews, F. M. 1979. *Scientific Productivity*. Cambridge: Cambridge University Press.

Astin, H. S. 1969. *The Woman Doctorate in America*. New York: Russell Sage Foundation.

Astin, H. S. and A. E. Bayer. 1975. "Sex Discrimination in Academe." In M. T. S. Mednick, S. S. Tangri, and L. W. Hoffman, eds., *Women and Achievement*. Washington, D.C.: Hemisphere.

Bandura, A. 1977. *Social Learning Theory*. Pp. 11–12. Englewood Cliffs, N.J.: Prentice-Hall.

Bayer, A. E. and H. S. Astin. 1972. "Sex Differentials in the Academic Reward System." *Science* 188: 796–802.

Bayer, A. E. and J. Folger. 1966. "Some Correlates of a Citation Measure of Productivity in Science." *Sociology of Education* 39: 381–390.

Berryman, S. E. 1983. *Who Will Do Science?* New York: The Rockefeller Foundation.

Bielby, W. 1991. "Sex Differences in Careers: Is Science a Special Case." In Harriet Zuckerman, Jonathan R. Cole, and John Bruer, eds., *The Outer Circle*. New York: Norton.

Bielby, W. and J. Baron. 1984. "Work Commitment, Sex-Role Attitudes, and Women's Employment." *American Sociological Review* 49: 234–247.

Centra, J. A. 1974. *Women, Men, and the Doctorate*. Princeton, N.J.: Educational Testing Service.

Clemente, F. 1973. "Early Career Determinants of Research Productivity." *American Journal of Sociology* 79: 409–419.

Cohen, J. E. 1980. "Publication Rate as a Function of Laboratory Size in a Biomedical Research Institution." *Scientometrics* 2: 35–52.

Cole, J. R. 1969. *The Social System of Science*. Ph.D. dissertation, Columbia University.

———. 1979. *Fair Science: Women in the Scientific Community*. New York: The Free Press.

———. 1987. "The Paradox of Individual Particularism and Institutional Universalism." In Jon Elster, ed., *Justice and the Lottery*. Cambridge: Cambridge University Press.

Cole, J. R. and S. Cole. 1973. *Social Stratification in Science*. Chicago: Chicago University Press.

———. 1976. "The Reward System of the Social Sciences." In C. Frankel, ed., *Controversies and Decisions: The Social Sciences and Public Policy*, pp. 55–88. New York: Russell Sage Foundation.

———. 1985. "Experts' 'Consensus' and Decision-Making at the National Science Foundation." In Kenneth Warren, ed., *Selectivity in Information Systems—Survival of the Fittest*. pp. 27–63. New York: Praeger.

Cole, J. R., S. Cole, and the Committee on Science and Public Policy. 1981. *Peer Review at the National Science Foundation: Phase II of a Study*. Washington, D.C.: National Academy of Sciences Press.

Cole, J. R., and H. Zuckerman. 1984. "The Productivity Puzzle: Persistence and Change in Patterns of Publication of Men and Women Scientists." In Marjorie W. Steinkamp and Martin L. Maehr, eds., *Advances in Motivation and Achievement*, vol. 2, pp. 217–258. Greenwich, Ct.: JAI Press.

———. 1987. "Marriage, Motherhood, and Research Performance in Science." *Scientific American* 255, 2: 119–125.

Cole, S. 1970. "Professional Standing and the Reception of Scientific Discoveries." *American Sociological Review* 76:286–306.

———. 1975. "The Growth of Scientific Knowledge: Theories of Deviance as a Case Study." In L. A. Coser, ed., *The Idea of Social Structure: Papers in Honor of Robert K. Merton*, pp. 175–220. New York: Harcourt Brace Jovanovich.

Cole, S., J. R. Cole, and L. Dietrich. 1978. "Measuring the Cognitive State of Scientific Disciplines." In Y. Elkana et al., eds., *Toward a Metric of Science*, pp. 209–251. New York: Wiley.

Cole, S., L. Rubin, and J. R. Cole. 1978. *Peer Review at the National Science Foundation: Phase I of a Study*. Washington, D.C.: National Academy of Sciences Press.

Cole, S., J. R. Cole, and G. A. Simon. 1981. "Chance and Consensus in Peer Review." *Science* 214: 881–886.

Crane, D. 1969. "Social Class Origin and Academic Success: The Influence of Two Stratification Systems on Academic Careers." *Sociology of Education* 42: 1–17.

Darwin, C. 1859. *The Origin of Species.* New York: Modern Library.

Duncan, B. and O. D. Duncan. 1978. *Sex Typing and Social Roles: A Research Report.* New York: Academic Press.

Feller, W. 1968. *Introduction to Probability Theory and Applications,* vol. 1. 3rd ed. New York: Wiley.

Foulkes, M. A. and C. E. Davis. 1981. "An Index of Tracking for Longitudinal Data." *Biometrics* 37: 439–446.

Fox, M. F. 1981a. "Sex, Salary, and Achievement: Reward-Dualism in Academia." *Sociology of Education* 54: 71–84.

———. 1981b. "Patterns and Determinants of Research Productivity Among Male and Female Social Scientists." University of Michigan, Preprint.

———. 1983. "Published Productivity Among Scientists: A Critical Review." *Social Studies of Science* 13: 285–305.

———. 1985. "Publication, Performance, and Reward in Science and Scholarship." In J. Smart, ed., *Higher Education: Handbook of Theory and Research.* New York: Agathon Press.

Gaston, J. 1973. *Originality and Competition in Science.* Chicago: University of Chicago Press.

———. 1978. *The Reward System in British and American Science.* New York: Wiley Interscience.

Gilbert, G. N. and M. Mulkay. 1984. *Opening Pandora's Box.* Cambridge: Cambridge University Press.

Hagstrom, W. O. 1965. *The Scientific Community.* New York: Basic Books.

———. 1971. "Inputs, Outputs and the Prestige of American University Science Departments." *Sociology of Education* 44: 375–379.

Hargens, L. L., J. C. McCann, and B. R. Reskin. 1978. "Productivity and Reproductivity: Fertility and Professional Achievement Among Research Scientists." *Social Forces* 52: 129–146.

Harmon, L. R. 1963. "The Development of a Criterion of Scientific Competence." In C. W. Taylor and Frank Baron, eds., *Scientific Creativity: Its Recognition and Development,* pp. 44–53. New York: Wiley.

———. 1965. *High School Ability Patterns: A Backward Look from the Doctorate.* Scientific Manpower Report, no. 6. Washington, D.C.: National Research Council.

Helmreich, R. L., J. T. Spence, W. E. Beane, G. W. Lucker, and K. A. Matthews. 1980. "Making It in Academic Psychology: Demographic and Personality Correlates of Attainment." *Journal of Personality and Social Psychology* 39: 896–908.

Kahle, J. B. and M. L. Matyas. 1985. "Equitable Science and Mathematical Education: A Discrepancy Model." In L. S. Dix, ed., *Women: Their Underrepresentation and Career Differentials in Science and Engineering,* pp. 5–41. Washington, D.C.: National Academy Press.

Knorr-Cetina, K. D. 1981. *The Manufacture of Knowledge.* Oxford: Pergamon Press.

Latour, B. and S. Woolgar. 1979. *Laboratory Life: The Social Construction of Scientific Facts.* Beverly Hills: Sage.

Long, J. S. 1978. "Productivity and Academic Position in the Scientific Career." *American Sociological Review* 43: 889–908.

Long, S. and R. McGinnis. 1981. "Organizational Context and Scientific Productivity." *American Sociological Review* 46: 422–442.

Maccoby, E. E. and C. N. Jacklin. 1975. *The Psychology of Sex Differences.* Stanford: Stanford University Press.

Marini, M. M. 1987. "Sex and Gender." In E. F. Borgotta and K. S. Cook, eds., *The Future of Sociology.* Beverly Hills: Sage.

Marini, M. M. and M. C. Brinton. 1984. "Sex Typing in Occupational Socialization." In B. Reskin, ed., *Sex Segregation in the Workplace: Trends, Explanations, Remedies,* pp. 192–232. Washington, D.C.: National Academy Press.

Marwell, G., R. Rosenberg and S. Spilerman. 1979. "Geographic Constraints on Women's Careers in Academia." *Science* 205: 1225–1231.

Merton, R. K. 1957. "Priorities in Scientific Discovery." *American Sociological Review* 22: 635–659.

———. 1968. "The Matthew Effect in Science." *Science* 159: 56–63.

———. 1973. *The Sociology of Science.* Chicago: University of Chicago Press.

———. 1987. "Three Fragments from a Sociologist's Notebooks: Establishing the Phenomenon, Specified Ignorance, and Strategic Research Materials." *Annual Review of Sociology* 13: 1–28.

Mittermeir, R. and K. D. Knorr. 1979. "Scientific Productivity and Accumulative Advantage: A Thesis Reassessed in the Light of International Data." *R&D Management* 9: 235–239.

Over, R. 1982. "Research Productivity and Impact of Male and Female Psychologists." *American Psychologist* 37: 24–31.

Over, R. and D. Moore. 1980. "Research Productivity and Impact of Men and Women in Psychology Departments of Australian Universities, 1975–1977." *Australian Psychologist* 15: 413–418.

Pfeffer, J. 1982. *Organizations and Organization Theory.* Boston: Pitman.

Price, D. J. deSolla. 1963. *Little Science, Big Science.* New York: Columbia University Press.

Reskin, B. 1977. "Scientific Productivity and the Reward Structure of Science." *American Sociological Review* 42: 491–504.

———. 1978a. "Scientific Productivity, Sex, and Location in the Institution of Science." *American Journal of Sociology* 83: 1235–1243.

———. 1978b. "Sex Differentiation and the Social Organization of Science." In J. Gaston, ed., *The Sociology of Science.* San Francisco: Jossey-Bass.

———. 1979. "Review of the Literature on the Relationship Between Age and Scientific Productivity. In *Research Excellence Through the Year 2000.* Washington, D.C.: Commission on Human Resources, National Academy of Sciences Press.

Rossi, P. 1979. "Vignette Analysis: Uncovering the Normative Structure of Complex Judgments." In R. K. Merton, J. S. Coleman and P. S. Rossi, eds., *Qualitative and Quantitative Social Research,* pp. 176–186. New York: The Free Press.

Spence, J. T. and R. L. Helmreich. 1978. *Masculinity and Femininity: Their Psychological Dimensions, Correlates and Antecedents.* Austin: University of Texas Press.

———. 1979. "Comparison of Masculine and Feminine Personality Attributes and Sex-Role Attitudes Across Age Groups." *Developmental Psychology* 15: 583–584.

Spence, J. T., R. L. Helmreich, and J. Stapp. 1975. "Ratings of Self and Peers on Sex Role Attributes and Their Relation to Self-Esteem and Conceptions of Masculinity and Femininity." *Journal of Personality and Social Psychology* 32: 29–39.

Waddington, C. H. 1940. *Organization and Genes.* Cambridge: Cambridge University Press.

Ware, J. H. and M. C. Wu. 1981. "Tracking: Prediction of Future Values from Serial Measurement." *Biometrics* 37: 427–437.

Weiner, N. 1956. *I Am a Mathematician.* New York: Doubleday.

Wilson, E. O. 1975. *Sociobiology.* Cambridge: The Belknap Press.

Zuckerman, H. 1970. "Stratification in American Science." *Sociological Inquiry* 40: 235–257.

———. 1977. *Scientific Elite: Nobel Laureates in the United States.* New York: The Free Press.

———. 1978. "Theory Choice and Problem Choice in Science." *Sociological Inquiry* 48:65–95.

———. 1989. "Accumulation of Advantage and Disadvantage: The Theory and Its Intellectual Biography." In C. Mongardini and S. Tabboni, eds., *L'Opera di R. K. Merton e La Sociologia Contemporanea,* pp. 153–176. Genova: Edizioni Culturali Internazionali (ECIG).

Zuckerman, H. and J. R. Cole. 1975. "Women in American Science." *Minerva* 13: 84 ff.

Zuckerman, H. and R. K. Merton. 1971a. "Age, Aging, and Age Structure in Science." In M. W. Riley, M. Johnson and A. Foner, eds., *Aging and Society: A Sociology of Age Stratification,* vol. 3. New York: Russell Sage Foundation.

———. 1971b. "Patterns of Evaluation in Science: Institutionalization, Structure and Functions of the Referee System." *Minerva* 9: 66–100. Reprinted in R. K. Merton, *The Sociology of Science,* p. 479.