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Of Bicycles, Bakelites, and Bulbs

Toward a Theory of Sociotechnical Change

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I also benefited from discussions with research groups in various places. Chapter 4 was largely written during my stay as visiting professor at the Technical University in Vienna. Chapter 5 received its penultimate and most radical revision during my visit to the Technical University of Denmark. The research group "Technological Culture" in Maastricht provided an important forum for discussing drafts of chapters 4 and 5. Tannelie Blom, Ton Nijhuis, Rein de Wilde (Maastricht), Rob Hagendijk (Amsterdam), Ulrik Jörgensen (Copenhagen), and Eduardo Aibar (Barcelona) have tried to help me avoid various pitfalls in the discussions of power in these last chapters (though I probably still fell into a good number of them). Ed Constant, Tom Misa, and Paul Rosen have provided stimulating discussion at various stages of writing.

Making a book, however, is not just a matter of academic research and teaching. In the final stage, the comments of two anonymous referees were stimulating and challenging. Bernie Carlson, Larry Cohen, and Trevor Pinch succeeded in critically following and shaping the project without jeopardizing our relationship as co-editors of the Inside Technology series. Melissa Vaughn did the crucial editing and production job of turning the manuscript into a book. Such were the professional ties, many of which have turned into friendships.

But the last—and in some respects most important—part of the weave has yet to be mentioned. This book could never have been written solely within the confines of academia. Liselotte, Else, and Sanne continually reminded me of this in their need for cooking and caring, and their claims to bicycle and football, to playing piano and cello. But mainly by just being there, three daughters provide a strong, continuous demonstration that life is more, and more complex, and more interesting, than the activities in the academic compartment of society. This book is dedicated to Tonny, who complements all those mentioned above as skeptical commentator, as supportive friend, as mother of the daughters, as love.

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Introduction

The stories we tell about technology reflect and can also affect our understanding of the place of technology in our lives and our society. Such stories harbor theories. But stories can be misleading, especially if they aim for neatness and therefore keep to the surface of events. This book will be about both stories and theory. I will start with some of the stories:

- In 1898 a female cyclist was touring the English countryside. She was dressed in knickerbockers, which seemed the most practical and comfortable clothing for a woman on a safety bicycle. After a good lap, she spotted an inn and decided to take a bit of refreshment. To her surprise, the proprietor refused to seat her in the coffee room and insisted that, if she wanted service, she would have to go into the public bar. The innkeeper's objection centered on the cyclist's clothes; evidently she did not think it proper for a woman to appear in public in anything but a long skirt. The cyclist objected, of course, and eventually brought her grievance to court, which sided with the right of the innkeeper to refuse service. This was not the end of the story, though. This lost case had an important afterlife as a symbol in the battle for women's rights. Can we say, then, that the design of this technological artifact, the safety bicycle, which allowed our cyclist to travel on her own and to choose a more comfortable form of dress, played a role in challenging traditional gender roles and building modern society?[1]
- "God said, 'Let Baekeland be,' and all was plastic." Few individual inventors have had as great an impact on society as did Leo Baekeland. This brilliant inventor created the first truly synthetic material to replace natural and seminatural materials such as ivory and Celluloid, and developed many of the applications that led society into the era of plastics. At first glance, Baekeland seems an exemplar of the American scientist-

entrepreneur. A poor Belgian immigrant to the United States, he worked his way up by cleverness and diligence, and by combining scientific discovery with commercial acumen. He became rich, served his new country during World War I in the Naval Consulting Board, and served humankind by giving it plastics. A longer look, however, shows that Baekeland was shaped not by a mythical act of creation but by several distinct sociotechnical traditions and cultures. It was only because he was enculturated in the technical and scientific practices of electrochemistry that he was able to escape the bondage of the Celluloid engineering tradition; but it was only because he was part of the Celluloid tradition that he undertook this research at all. Can one assert, then, that even cases of seemingly unique individual ingenuity and creativity are always linked to wider social interactions and cultural processes?

- When the General Electric Company tried to introduce the fluorescent lamp in 1938 as a source of color lighting, they quickly found themselves in a battle with the electric utilities, who feared that the lamp's high efficiency would jeopardize their electricity sales. Consumers and lighting engineers, however, were so eager to buy this new type of lighting that the utilities were forced to accept some form of the lamp. After a fierce confrontation that threatened the established power relations in the electric lighting business, an agreement was reached under which the lamp's design was substantially changed. This renewed cooperation did not escape the notice of the Antitrust Division of the federal government, which decided to sue General Electric and the utilities for forming a cartel. General Electric, in response, successfully lobbied the War Department into fending off this suit because, they argued, such litigation would endanger the war effort. The fluorescent lamp was thus the product of a complex economic power play in which General Electric, the electric utilities, the U.S. government, and consumers all played roles. Conversely, the power map of the electric manufacturing scene in the United States was substantially modified by the introduction of the new lamp. Can we then say that artifacts are not only shaped by the power strategies of social groups but also form part of the micropolitics of power, constituting power strategies and solidifying power relations?

These three stories highlight many of the issues that this book will address. For example, how can gender relations affect the design of a bicycle? Although it later became an instrument for women's emancipation, the first cycles in fact reinforced the existing "gender order"—women were only allowed to ride on tricycles, and preferably on two-

Figure 1.1
Women's emancipation: the wheel of the past and the wheel of the present (reprinted from Palmer (1958: 101).

seaters with a male as chaperon. It is therefore appropriate to ask: What impact did the evolution of bicycle design have on society? How did it shape social relations (see figure 1.1)? This is the companion issue of this ② book, for we shall explore both the social shaping of technology and the technical shaping of society.

Framing these issues in terms of "society" and "technology" should not obscure the fact that technology and society are both human constructs. Technology is created by engineers working alone or in groups, marketing people who make the world aware of new products and processes, and consumers who decide to buy or not to buy and who modify what they have bought in directions no engineer has imagined. Technology is thus shaped not only by societal structures and power relations, but also by the ingenuity and emotional commitment of individuals. The characteristics of these individuals, however, are also a product of social shaping. Values, skills, and goals are formed in local cultures, and we can therefore understand technological creativity by linking it to historical and sociological stories. This is the second set of central issues in this book: How can we link the interactions of individual actors such as engineers and users to societal processes? And how can we link the analysis of micro case studies to an understanding of macro processes of societal and technological change?

This linking of micro stories with macro structures involves questions about the internal structure of technology: about the nature of inventors' work, about the interaction of knowledge, skills, and machines, about the epistemology of technology. But it also involves the politics of technology. The quick summary of the story of the fluorescent lamp showed how it was shaped by the power relations of General Electric and the utilities and eventually helped shift those relations. How do artifacts become instruments of power? And conversely, how do power relations materialize in artifacts? Some artifacts are more obdurate, harder to get around and to change, than others. Who was in a position to modify the fluorescent lamp design that was proposed in 1938, and who was compelled to "take it or leave it" as it was? Exploring the obduracy of technology offers one way to gain understanding of the role of power in the mutual shaping of technology and science.

From Detour to Main Route

This book is the result of a personal detour that turned into a main route. My detour started from sociopolitical concerns about the role of technology in society and then carried me into academia. Like many Dutch engineering students in the 1970s, I was drawn to the science-technology-society (STS) movement, whose goal was to enrich the curricula of both universities and secondary schools by offering new ways to explore issues such as the risks of nuclear energy, the proliferation of nuclear arms and other new weapons systems, and environmental degradation. The movement was eventually quite successful, especially in the natural science and engineering faculties, where small groups were established to teach STS courses and some of the courses even became part of degree requirements. The secondary school science curriculum was also reformed to include STS issues, both optional and integrated into the regular physics program. At the same time, STS students and staff were among the central actors in the movement against the extension of nuclear power and the introduction of the "neutron bomb" and cruise missiles. After gaining access to the academy, however, and during our political struggles, we were increasingly confronted with the crudeness and inadequacy of our models of science and technology development. We were working in many instances on our gut feelings about technology, but were not able to back our positions with theoretical arguments. This is what spurred my detour into academia—a desire to see if I could help devise new ways to think about the development of technology and its relationship to society.

Many other researchers from the early STS ranks made similar detours. Now, two decades later, science and technology studies is a well-established discipline with chairs, journals, societies, and both undergraduate and graduate programs—everything that a respectable academic discipline requires.[2] But did this detour yield the politically relevant insights that we needed fifteen years ago? Or does our new discipline worry too much about its status in the academy? Have all our activists turned into scholars? The central argument of this book will be that STS can retain its edge even in the academy, that what started out as a detour can be turned into a main route without necessarily losing its societal relevance.

At the beginning of my detour I found at least three models open to me. First, there were those who looked down their noses at mere storytellers. These were the scholars, often with backgrounds in the social sciences, who advocated general typologies, precise conceptual definitions, and macrotheoretical schemes that could produce "real" insights and explanations. Second, there were those who poked fun at any theoretical generalization beyond the uniquely detailed story. These students, often of the historians' tribe, scorned the empty theoretical boxes and abstract schemata that did not display any familiarity with what "really" went on. Third, there were the political activists, who considered any detour into academia a betrayal of the immediate societal tasks that should be the constant overriding concern of critical intellectuals.

What finally changed my detour into a main route was the conclusion that all three approaches are equally necessary. I believe that effective societal action on issues of technology and science cannot do without scholarly support, while academic technology studies have much to gain from engagement with politically relevant issues. And only an integration of detailed empirical case studies with general conceptual frameworks can build this link between academia and politics. I have come to believe that an integration of case studies, theoretical generalizations, and political analyses is called for and possible, both *to understand* the relations between technology and society and *to act* on issues of sociotechnical change. This book will start with stories, then generate theoretical concepts, and finally argue for politics. The idea of a gap between the real world and academia, at the basis of the "detour" metaphor, proved misleading.

Guideposts

What guideposts can lead us as we embark on this journey to an integrated understanding of the STS problematic? The past decade has seen the emergence of a new research program in technology studies.[3] This program, commonly labeled "constructivist studies of technology," is based mainly on the combination of historical and sociological perspectives. Infusions from economics and philosophy have hitherto been quite small, although efforts are now being made to incorporate work from these disciplines into constructivist research.[4] A central adage for this research is that one should never take the meaning of a technical artifact or technological system as residing in the technology itself. Instead, one must study how technologies are shaped and acquire their meanings in the heterogeneity of social interactions. Another way of stating the same principle is to use the metaphor of the "seamless web" of science, technology, and society, which is meant to remind the researcher not to accept at face value the distinctions between, for example, the technical and the social as these present themselves in a given situation.

Within the constructivist research program we can distinguish three lines of work: the systems approach, the actor-network approach, and the social construction of technology (SCOT) approach. This book has developed in the main from SCOT studies, but I believe that the arguments are of general relevance for the whole spectrum of modern constructivist studies.

① One pitfall that the newer research programs are designed to avoid is any implicit assumption of linear development. Such assumptions were often found in earlier technology studies, sometimes at the level of the singular invention (figure 1.2) and sometimes in the genealogy of related

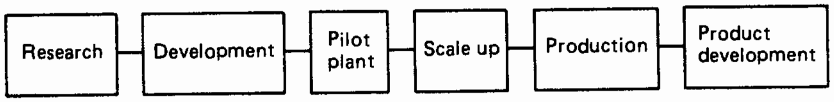

Figure 1.2
A six-stage model of the innovation process.

innovations (figure 1.3). The problem is that once students start expecting linearity, they blind themselves to the retrospective distortions that linear descriptions almost inevitably require. Too easily, linear models result in reading an implicit teleology into the material, suggesting that "the whole history of technological development had followed an orderly or rational path, as though today's world was the precise goal toward which all decisions, made since the beginning of history, were consciously directed" (Ferguson, 1974: 19). To name Lawson's bicycle "the first modern bicycle" is an example of such a false linearity, as I will show in the next chapter. This label seems appropriate at a surface level because this was the first bicycle with two relatively low wheels and a chain drive on the rear wheel. It was, however, at least in a commercial sense, a complete failure, and the relevance of the label "first" is therefore questionable. Bicycles such as the Star and the Geared Facile did much better commercially, but because they do not fit into a simple linear scheme, they are often written off into the margins of the story.

A second pitfall the constructionist programs are designed to avoid is what one might call the asymmetrical analysis of technology. Staudenmaier (1985) observed that in the first twenty-five volumes of the journal *Technology and Culture*, only nine articles were devoted to the analysis of failed technologies. The focus on successful innovations suggests an underlying assumption that it is precisely the success of an artifact that offers some explanatory ground for the dynamics of its development. Many histories of synthetic plastics, for example, start by describing the technically sweet characteristics of Bakelite. These features are then used implicitly to position Bakelite at the starting point of the glorious development of the synthetic plastics field, as in Kaufman's (1963: 61) quotation of God at the beginning of this chapter. However, a more detailed study of the developments of plastic and varnish chemistry following the publication of the Bakelite process in 1909 shows that Bakelite was at first hardly recognized as the marvelous synthetic resin it later proved to be.[5] A historical account founded upon the retrospective success of Bakelite (its "working") leaves much untold. More specifically, such an

pitfall

But any/all stories leave "much untold"!

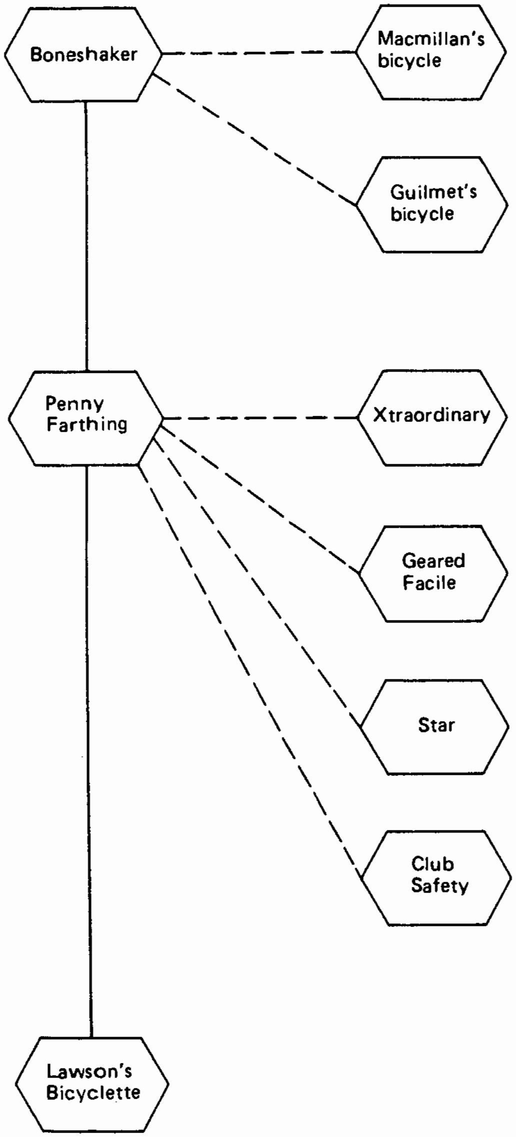

Figure 1.3
The traditional quasi-linear view of the development of the high-wheeled Ordinary bicycle until Lawson's bicycle. The solid lines indicate successful development, while dashed lines indicate failure.

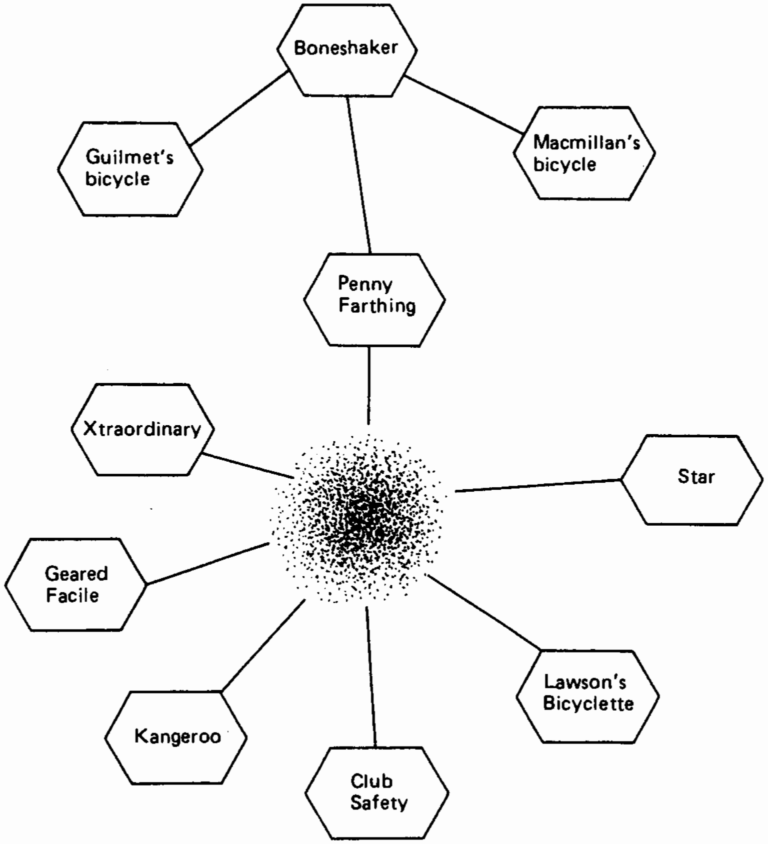

Figure 1.4
A nonlinear representation of the various bicycle designs since the high-wheeled Ordinary bicycle. The various designs are treated equally, without using hindsight knowledge about which design principles eventually would become most commonly used.

account misses the interesting question of how Bakelite *came to be seen as* a practical molding material; instead, in these asymmetrical accounts Bakelite simply *was so* all along. (Figure 1.4 shows a possible visualization of an alternative analysis for the bicycle example—symmetrical and without a linearity assumption.)

Other beacons to guide our journey come from the individual disciplines on which STS studies draw. For example, a key debate in the history of technology[6] has involved the primacy of internalist versus contextualist (or externalist) studies. Internalists maintain that we can understand the development of a technology only if we start with an understanding of the technology in all its minute details. Contextualists, by contrast, claim that the economic, social, political, and scientific context of a technology is as important to its development as are its technical design characteristics. I lean toward the contextualist side of this debate. To understand the development of bicycle designs, for example, I think it is important to know about the industrial development of Coventry, a visit to the Queen by the English "Father of the Bicycle," and the early professional bicycle races. At the same time, I believe that details are important, and I hope to demonstrate that it is only by going down to the "nuts and bolts" level of analysis that we can gain insight in the *design* development of technology.[7] By the end of the book I will also take one additional step outside the "pure" contextualist path, arguing that, rather than being satisfied with the distinction between technology and its context as the basic dimension for analysis, we must figure out a way to take the common evolution of technology and society as our unit of analysis.

Technological creativity has been another long-standing research topic from which we can draw guideposts. One key issue that absorbs many researchers is uncovering the "Mother of Invention." Is it "necessity," implying that an invention will sooner or later emerge out of felt needs, independent of individual creativity? Or is it the "act of ingenuity," without which needs might never be fulfilled (but perhaps not explicated either)? In arguments for the individual act, one still sees numerous references to the claim by Jewkes et al. (1958) that the majority of inventions in the twentieth century have resulted from individual work rather than large-scale organized research. Often, a stress on the role of the individual inventor is accompanied by a declaration that the topic is immune to research: "like a poet or an artist, therefore, the inventor participates in an act of creation, and no amount of theoretical construction can encompass the terms on which such creativity can be achieved."[8]

Nevertheless, two lines of research are now bearing fruit. The first focuses on inventors as system builders, thus combining analysis of individual creative actors with descriptions of their systemic constructs and contexts.[9] The second combines history of technology with the insights of psychology to explore acts of individual creativity.[10] A quite opposite approach is possible as well. Rather than taking individual ingenuity as given, this approach tries to describe the label "individual genius" as the result of a series of attribution processes by which one person eventually "wins all." My approach to the problem of creativity is probably closest to this last one. I tend to analyze the development of technology (including its invention) as a social rather than a psychological process. I will not argue, however, that individual engineers and their histories do not matter. For example, I found it quite illuminating to delve into Baekeland's early work in photographic chemistry as a source for his research gusto (he dissolved his father's watch when he needed more silver), and I found his work with the new electrochemical plants at Niagara Falls an aid to understanding his experience with upscaling chemical production. But I will also introduce a conceptual framework that will link these stories about individual inventors to a sociological analysis of their positions in a specific technological culture.

Yet another guidepost comes from political science. Power has always held a peculiar place in studies of technological development. It is hardly ever invoked by the historians as part of their explanations of events—mainly, I think, because their stories do a much better job of explanation than any crude "power" concept might. The older sociology of technology did not address either the question of technological development or that of the role of power in that process.[11] Recent sociohistorical studies of technology have also avoided the use of "power" as a central category, not because everyone is equal, or because there are no hierarchical relations between particular individuals and social groups, but because explanations in terms of power so easily result in begging what seem to be the most interesting questions. Thus it is just not very insightful to state that the introduction of the fluorescent lamp was held up because the electric utilities were more powerful than General Electric; nor is it illuminating to state that the fluorescent lamp finally appeared on the market because General Electric proved more powerful. Instead, I want to raise the question of which strategies the utilities and General Electric (and other companies, and the U.S. government, and all the other actors) employed to create a certain outcome—an outcome that can then be conveniently summarized by drawing a map of the power distribution. In this analysis of power strategies, I will especially focus on the role of artifacts.

Project Design

The core of this book is formed by three case studies: the safety bicycle, Bakelite, and the fluorescent lamp. In selecting these cases, I employed two crude criteria. The first was to focus on the actual design process of technology, on the details of the technical machines and processes. The second was to secure an empirical base broad enough to render generalizations interesting.

The first criterion suggested implicitly what in this study would constitute "technology." The aim was to select cases that would allow a focus on the "hard" contents of technology rather than its systemic aspects. I therefore decided to focus on "elementary innovations" rather than technological systems, and this led me to the bicycle rather than the automobile, Bakelite rather than synthetic materials in general, and the fluorescent lamp rather than electric lighting.

An intuitive and commonsense idea about what "technology" and "society" are, and what there is to be asked about their developmental process, further informed the selection. However, what starts out as an intuitive assumption about the object of research of this study will by the end of this book have become a key question: What constitutes "an artifact," "design," "technical change," "technology," "society"? The object of research will thus, in the course of the book, evolve from elementary technical artifacts to "sociotechnical ensembles."

My second criterion was founded on a desire to create a relatively broad empirical base for generalizations. Several dimensions were used to check the heterogeneity of alternative cases: the period in which the invention was made, the disciplinary background of the invention, the industrial context, the intended market, and the invention's process or product character. Thus I selected cases that, taken together, span most of the period after the second industrial revolution: the bicycle covers 1860–1890; Bakelite, 1880–1920; and the fluorescent lamp, 1930–1945. The cases are also varied in terms of their underlying engineering background: mechanical engineering (the bicycle), chemical engineering (Bakelite), and electrical engineering (the fluorescent lamp). With respect to industrial context, the cases move from a blacksmith's workshop (bicycle) to an early scientific laboratory (Bakelite) to a large industrial laboratory (fluorescent lamp). The bicycle was exclusively aimed at the consumer market, Bakelite as a molding material was aimed at the industrial market, and the fluorescent lamp has in this respect a hybrid character. In the patent literature a distinction is often made between product and process types of inventions. The bicycle and the fluorescent lamp are clearly both product inventions, while Bakelite is primarily a process invention.

Table 1.1
Requirements for a theory of technological development

1. Change/continuity	The conceptual framework should allow for an analysis of technical change as well as of technical continuity and stability.
2. Symmetry	The conceptual framework should take the "working" of an artifact as *explanandum*, rather than as *explanans*; the useful fuctioning of a machine is the result of sociotechnical development, not its cause.
3. Actor/structure	The conceptual framework should allow for an analysis of the actor-oriented and contingent aspects of technical change as well as of the structurally constrained aspects.
4. Seamless web	The conceptual framework should not make a priori distinctions among, for example, the social, the technical, the scientific, and the political.

Because I wanted to create a relatively broad base of data, I chose to present a larger number of cases using mainly published sources rather than one or two cases using unpublished archival material.[12] The studies are not intended primarily to unveil new historical facts, though they are presented in such detail that I hope readers will come away with new insights into the events they describe. I expect, however, that the primary benefit of the book will come from the generalizations made on the basis of the case studies–from the surplus value of the comparison of cases. It is to the requirements for this theoretical framework that I turn now (see table 1.1).

Requirements for a Theory of Sociotechnical Change

Elster (1983) has distinguished two approaches to the study of technical change. The first conceives of technical change as a rational, goal-directed activity. The second places emphasis on technical change as a process of trial and error, as a cumulative result of small and mostly random modifications. Two decades of studies in the sociology of scientific knowledge have stressed the contingent character of scientific development, and one of the basic assumptions of this book is that an analogous approach will be fruitful for studies of technical development.[13] This suggests that trial-and-error models, often cast in evolutionary terms, have specific advantages over models that stress the goal-oriented character of technological development. In the SCOT model that will be developed in this book I will also try to account for the contingent character of technical development, but will do so without employing a truly evolutionary framework.[14]

An emphasis on contingency seems to be the historian's delight as much as the sociologist's curse, offering no structuralist explanations for human action but free rein for individual actors. The other side of the coin, however, is that too much contingency would result in actors who have no meaningful history of their own: If there are no systematic, structural constraints, there are no limits to the spectrum of possibilities. There may be constraints, but they are contingent and unpredictable themselves. Therefore, evidently, one requirement for a theory of technical change is that it should be able to show how constancy and continuity exist in history, and under what conditions they exist. It should allow us to account not only for technical change but also for the stability of artifacts. If only rupture and revolution had a place in the analysis, while flow and evolution did not, the resulting framework would turn into (some) sociologist's delight and (some) historian's curse. Setting up such a truly dynamic conceptual framework is a notoriously difficult task. The typical way to tackle this problem is to give a static description and then add the time dimension—but to leave the concepts intrinsically static. Following this approach, one might try to explain the ability of a bicyclist to ride upright by drawing on a model of the bicycle as a pair of scales, with the bicyclist achieving balance by equating left- and right-hand forces.[15] The equilibrium of a rolling bicycle can, however, only be understood by using the intrinsically dynamic concept of "angular momentum." To meet the first requirement, our conceptual framework must have a similarly dynamic character.

Earlier in this chapter I discussed the idea of asymmetrical analysis—analysis in which the success and the failure of artifacts are explained in different terms. Using the "working" of an artifact as an *explanans* in the study of technology seems equivalent to using the "hidden hand of Nature" as an *explanans* in studies of science. That is to say, it was often assumed that scientific facts had to turn out the way they did because that is the way Nature dictated them to be. Recent science studies have called for an explanation of Nature as the result, instead of the cause, of scientific work. Similarly, for a theory of technology, "working" should be the *explanandum*, not the *explanans*. The "working" of a machine is not an intrinsic property of the artifact, explaining its success; rather, it should figure as a result of the machine's success. Thus, the success or failure of an artifact are to be explained symmetrically, by the same conceptual framework. An asymmetrical explanation might, for example, explain the commercial success of an artifact that we now consider to be working by referring to that "working," while the failure of that same artifact in another context might be explained by pointing at social factors. In a symmetrical explanation, "working" and "nonworking" will not figure as causes for a machine's success or failure. The claim is not that "working" is merely in the eye of the beholder, but that it is an achievement rather than a given. Understanding the construction of "working" and "nonworking" as nonintrinsic but contingent properties is the second requirement for the theory of technical change I shall try to develop.

The third requirement, pertaining to the actor/structure dimension, is closely related to the change/constancy requirement. The emphasis on the contingent character of technical change may seem to imply that anything is possible, that each configuration of artifacts and social groups can be built up or broken down at will. This, of course, cannot be: A theory of technology proposing such a view of our technological society clearly underestimates the solidity of society and the stability of technical artifacts. A theory of technical development should combine the contingency of technical development with the fact that it is structurally constrained; in other words, it must combine the strategies of actors with the structures by which they are bound.

The final basic assumption in my theoretical project is that modern society must be analyzed as a seamless web. The analyst should not assume a priori different scientific, technical, social, cultural, and economic factors. Rather, whatever creases we see are made by the actors and analysts themselves. Another way of expressing this idea is to recognize that a successful engineer is not purely a technical wizard, but an economic, political, and social one as well. A good technologist is typically a "heterogeneous engineer" (Law, 1987).

The metaphor of the seamless web has implications not only for empirical work but for our theoretical framework as well. I propose that we require our theoretical concepts to be as heterogeneous as the actors' activities. If we would do otherwise, the old a priori distinctions would return through the back door by the step of generalization, after having been kicked out through the front door by empirical research. The fourth requirement for a conceptual framework is thus not to compel ourselves to make any a priori choices as to the social or technical or scientific character of the specific patterns that we see by applying it.

To develop this empirically based theory of sociotechnical change, we need a descriptive model that will help us create a set of case studies that can be compared and combined in the process of developing generalizations. The descriptive model should allow analysts to get into the black boxes of the various cases, but also to get out again to compare case descriptions. Thus the model should strike a fine balance between describing the "nuts and bolts" and staying at a sufficient analytical distance to allow for cross-case comparisons. The development of such a descriptive model will be the main purpose of the second chapter, while in the third and fourth chapters the theoretical framework will be developed.

Book Design

The broad aim—to start from the more strictly disciplinary research questions of the history and sociology of technology, but to work toward an interdisciplinary result—implies certain constraints on form. This academic detour is built up from many smaller detours—sociological detours for historians and historical detours for sociologists. I can only hope that each detour will be attractive enough to be followed through by readers of whatever background, and that in the end the results will prove the detours worthwhile. These results should also yield the conclusion that what started out as a series of detours has turned out to be a new main route toward interdisciplinary STS studies.

At the outset, I have tried to use different styles of writing for the narratives and for the theoretical analyses and model building, highlighting the disciplinary character of both parts. Toward the end of the book the alternation between narrative and theoretical intermezzi fades away, and both blend into a single STS vocabulary. The narrative will present a thick description with many historical details. The cases per se merit such detailed descriptions—each offers a fascinating story of technical development and engineering life—but they also allow readers to check the interpretations I will propose during the theoretical detours. The theoretical framework, on the other hand, will be presented quite explicitly as a formal model. This is done for reasons of candor and clarity: It will allow more transparent discussions of the strengths and weaknesses of the theoretical framework. That theoretical framework does provide a coherent view of the joined development of society and technology; but it does not represent a closed world, outside of which no stories can be told. The aim, then, is not to make a model that pretends to explain all of technological development. The model will not be a set of narrowly defined concepts to be employed indiscriminately in empirical research. Rather, it will be a heuristic device, a set of sensitizing concepts that allow us to scope out relevant points, but one that will require adaptation and reformulation for use in new instances.

If this book has any usefulness as a teaching text, it will come from this combination of empirical case studies with theoretical modeling. I do not envisage the book as an instrument primarily meant to educate students about either the SCOT model or the details of the bicycle, Bakelite, or the fluorescent lamp. What I do hope is that the book will be useful in two other respects. First, it should make students think about the interplay of empirical research and theoretical modeling, about the relations between case studies and conceptual frameworks. Second, it should introduce students to recent constructivist perspectives in technology studies by putting one approach on the test bench. Finally, of course, I hope that the "detour-becomes-main-route" thesis will lead to high-spirited discussions about the relationships between society and technology, about the future of STS studies, and about one's societal roles and responsibilities as engineer, social scientist, or citizen.

In a way, this is an effort to write four books in one. The first three are the case studies, which focus on design, biography, and economics, respectively. The fourth is the combination of the first three, presenting a comparative analysis of changes in technology and society. All together I hope they will make the case for combining empirical case studies with theoretical analysis to strengthen the link between academic STS studies and politically relevant action.

2

King of the Road: The Social Construction of the Safety Bicycle

2.1 Introduction

Before the bicycle became "King of the Road,"[1] it was the "Prince of Parks." Aristocratic young men drove high-wheeled bicycles in Hyde Park to show off for their lady friends. The high-wheeled machine was not meant to provide ordinary road transportation, however, or to enable families to tour the countryside. These transportation and touring aims would be fulfilled by the safety bicycle—a low-wheeled vehicle with a diamond frame and a chain drive on the rear wheel—in the 1880s and 1890s. The process of emergence of this new bicycle will form the focus of this chapter.[2]

Why did the safety bicycle emerge only after the detour of the high-wheeled bicycle? A review of bicycle history shows an increase and subsequent decrease of front-wheel diameter, beginning and ending at about 22 inches, with a maximum of some 50 inches in between. The main difference between the first and last bicycles is the mechanical means of their propulsion: boots on the ground for the former versus a chain drive on the rear wheel for the latter. In retrospect, it seems that all the technical elements needed to modify the first bicycle (a "running machine") into the safety bicycle had been available since the time of Leonardo da Vinci. Why, then, did it take more than half a century for gears and a chain drive to appear on a working bicycle? What strange detour was this from the sure path of technical progress?

The high-wheeler has been described as a mechanical aberration, a freak. Its faults were its instability, the insane difficulty of getting on and off, and the fact that the large front wheel was driven and steered at the same time, which could be very tiring on the arms (Ritchie, 1975: 122). This will be the leading historical question of this chapter: How can we understand this detour as part of the construction of the safety bicycle?

The chapter has a theoretical as well as a historical goal. We will "extract" a descriptive model from the story of the bicycle, and then test this model by applying it to the other cases studies in the book.

I will start with an impressionistic sketch of early bicycle history, from the first machines up to the high-wheeled Ordinary bicycle. There follows a more detailed account of the specific groups involved in the transformation of the bicycle from high-wheeler to safety bicycle. I will then interrupt the flow to introduce the first element of the descriptive model: the idea of *relevant social groups.* A second methodological section will focus on problems involved in describing technical artifacts. The sixth section then shows how several solutions to the "problems" of the high-wheeler, especially the problem of safety, were designed in the form of alternative bicycles. This suggests the introduction of a crucial concept for our descriptive model: *interpretative flexibility.* The invention of the air tire—or rather its reinvention—is recounted in the next section. This proved to be a significant step in the formation of the safety bicycle and leads naturally to the introduction of the third and fourth elements of the descriptive model: *closure* and *stabilization.* The chapter closes by tracing in detail the stabilization process of the safety bicycle.

2.2 Prehistory of the Bicycle: From "Running Machine" to Ordinary

Leonardo da Vinci seems to have thought about the possibility of a humanly propelled vehicle that would be stable even though it had only two wheels (figure 2.1). The light-brown coloring of the drawing suggests that the machine was to be made of wood; it had wheels of equal size, a saddle supported by the rear axle, and a chain drive on the rear wheel. Da Vinci's role in this design has not been proved, although it is likely that the drawing was made in his atelier, thus suggesting his indirect involvement at least. The bicycle drawing in the *Codex Atlanticus* was found during a recent restoration. Data about da Vinci's pupil Salai, who is mentioned on the pages, suggest that the drawing was made around 1493 (Reti, 1974), at which time da Vinci was engaged in designing gears and chains, one of which looked much like that depicted in the sketch. There is no indication, however, that this vehicle was ever constructed.

The first vehicles with two wheels arranged in line were built at the end of the eighteenth century. Although there are some reports about machines of even earlier date (Minck, 1968; Daul, 1906), most accounts identify the Célerifère as the first such vehicle (figure 2.2). It had the form of a wooden horse with two wheels. Its maker is unknown. The Comte de Sivrac, a young man known for his eccentricities, is reported to have been seen riding it in 1791 in Parisian parks. While sitting on the "horse," he pushed the vehicle forward with his feet. Because there was no steering wheel, he had to go through a tedious procedure whenever he wanted to make a turn: stop, lift the machine, and then put it down facing the new direction. De Sivrac worked hard to earn the applause of the people walking in the Bois de Boulogne: "Il s'arrête de temps en temps, fort essouflé, fort fripé, mais toujours souriant."[3] Three years later the machine, renamed the *vélocifère,* had become a pastime for some of the more dashing young men of Paris, who showed their skills in the gardens of the Palais-Royale. Races were even held along the Champs Elysées. The initial enthusiasm faded quickly, however, after several riders strained themselves in lifting the heavy machines and others suffered rupture of the groin (Woodforde, 1970).

The turning problem was solved in 1817 by Karl Friedrich Christian Ludwig, Freiherr Drais von Sauerbronn in Mannheim. Karl von Drais,

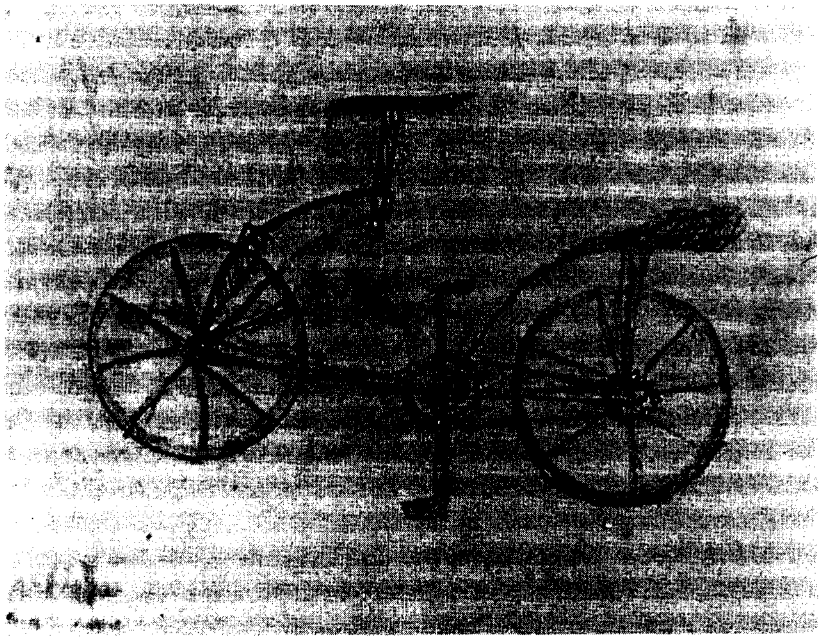

Figure 2.1
A bicycle-like machine, probably drawn by one of Leonardo da Vinci's pupils (*Codex Atlanticus,* page 133 verso; photograph courtesy the Biblioteca-Pinacoteca Ambrosiana in Milano).

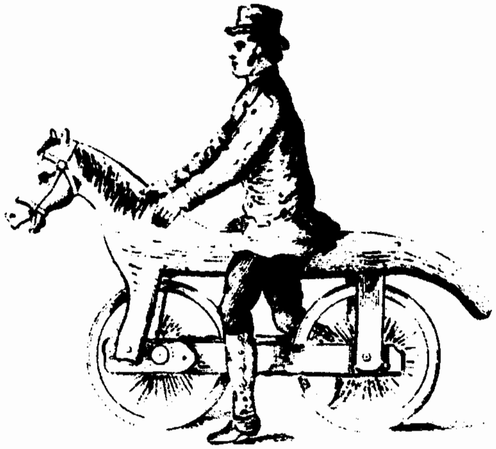

Figure 2.2
The "Célerifère" of 1791, in 1793 renamed the "vélocifère."

as he is generally known, was employed by the Baden court as master forester and chamberlain. His true calling, however, was mechanical construction. He invented several machines, such as a meat chopper, a typewriter, and a periscope, which left no deep trace in history. In 1817, however, he constructed a *Laufmaschine*, a "running machine" that consisted of a wooden frame with two wooden wheels of equal size positioned in line; the front wheel was able to turn. Between the wheels, on the frame, a cushioned saddle was mounted (figure 2.3). In front of the saddle was a cushioned bar on which the underarms could be rested. In the first version, steering was done with this bar; later Drais provided a separate steering handle in front of the resting bar.[4] He moved his machine forward by pushing on the ground with his feet, which were suitably protected by iron toe caps worn on his shoes (Croon, 1939; McGonagle, 1968; Lessing, 1990).

On 12 January 1818 Drais acquired a Baden patent with a validity of ten years for his invention. He built and sold quite a number of "running machines." Unofficially his Draisienne, as he liked to call it after its demonstration in Paris, was recognized as a road vehicle: On Saxon road signs it was placed under the rubric of *Fuhrwerke* ("machine for moving"). Probably to demonstrate its military usefulness, Drais drove his Draisienne from Karlsruhe to the French border in the short time of four hours. In other races against the clock he showed that he could drive significantly faster than a stagecoach (Klinckowstroem, 1959; Croon, 1939).

Figure 2.3
The "running machine" or "Draisienne," constructed by Karl Drais von Sauerbronn in 1817. The photo shows a colored lithograph of the inventor on his machine, probably published in the *Weimarian Journal for Literature, Art and Fashion* in 1820, with the caption "Der Freiherr von Drais. Inventor of the fast-running machine. Known fast and sharp thinker." The technical details of the lithograph are correct in every aspect. The poplars in the background are reminiscent of those on the road to Schwetzingen, the hills belong to the Odenwalt mountains. (I am grateful to Prof. H. E. Lessing for offering me this picture as well as its interpretation. See Lessing (1990) for a richly illustrated history of von Drais's machine. Photograph courtesy of the Städt. Reiss-Museum, Mannheim.)

In the beginning, press comments were positive. The German post adopted a few machines for its postmen (Rauck et al., 1979). Drais tried to establish a manufacturing firm, but this venture did not take off. Then the auditor's office prevented the German post from buying more Draisiennes because of the wear on the postmen's shoes (Rauck et al., 1979). The Draisienne became an object of ridicule for caricaturists, pedestrians, and schoolboys. Drais himself, running into an English horseman who poked fun at the machine and its rider, started an argument that ended in a fight. By the end of the 1840s his situation was rapidly deteriorating, both socially and psychologically, probably because of inherited epilepsy (Lessing, 1990). It is reported that when he drove past the city hall in Karlsruhe, he was often invited by the sentry to drink a pint of beer; in return, he had to ride down the stairs in front of the hall on his Draisienne, which often resulted in a kind of "salto portale." Drais died, poor and disillusioned, in Karlsruhe on 10 December 1851 (Croon, 1939).

In other countries, notably England, the Draisienne had more success. Dineur in France, Johnson in England, and Clarkson in the United States had, in the name of Drais, taken out patents on the invention in 1818 and 1819. Denis Johnson in particular tried hard to stimulate the use of what he liked to call the "pedestrian curricle" in England. The machine became commonly known as the hobbyhorse or dandyhorse. He developed a version for women in 1819, and in 1820 he organized an experiment of employing hobbyhorses for postmen. In America as in England, several "riding schools" were established. Hundreds of hobbyhorses were produced and sold. But it appeared to be only a craze. The new sport seems to have been vaguely irritating to the general public, perhaps because the riders used the best footpaths, perhaps because they just looked silly. Going downhill was a thrill, but without brakes it was quite dangerous, and it was hard to be graceful when you had no place to rest your feet. A well-known joke was that users of the hobbyhorse could ride in their carriage and walk in the mud at the same time. Moreover, blacksmiths and veterinarians saw a direct economic threat in the vehicle. Blacksmiths are reported to have smashed hobbyhorses that passed through their villages. This horse, they pointed out, required no shoeing (Woodforde, 1970).

The lack of comfort posed another problem for many users. The wooden or iron-clad wheels, the rigid frame, and the potholed roads resulted in a rough ride. Moreover, the movement of the body, shifting over and bumping up and down in the saddle, caused strains and not a few hernias. Another problem was that steering—the key trick in the "craft" of riding a modern bicycle—could hardly be used to keep the rider's balance.[5] When one looks closely at the Draisienne, it becomes obvious that steering must have taken a lot of force: The friction of the crossbar sliding under the frame backbone was quite great because the turning point of the front fork was positioned relatively far forward. You had to use your feet to balance the vehicle while also using them to give the Draisienne its forward momentum.

The problems of the hobbyhorse were recognized by users at the time, but Drais had not wanted to revise his machine fundamentally once he had provided the extra steering handle. (Occasionally he did provide extras such as brakes and saddles whose height could be adjusted.) Others, however, did try to find solutions to the more fundamental problems and thus improve the hobbyhorse. Johnson, for example, constructed an iron version of the machine, and this enabled him to improve the bearing of the steering axis. With such a tube bearing, the axis of the steering front wheel could be positioned more precisely and the friction created by turning the wheel could be greatly reduced, so that the steering mechanism could be used to keep the vehicle upright. Indeed, this has remained the most effective way to do so ever since. In retrospect, we realize that this development raised in principle the possibility of getting one's feet up off the ground and keeping one's balance by steering. However, the problem of muddy feet stayed unresolved for some decades.

Several methods were tried to raise the feet off the ground. As early as 1839, Kirkpatrick MacMillan, blacksmith of Courthill, Dumfriesshire, Scotland, added cranks to the rear wheel of his hobbyhorse (see figure 2.4). These cranks were driven by a forward and backward motion of the feet on two long treadles. The machine seems to have functioned quite well, although MacMillan is said to have caused the first bicycle road accident in 1842 by knocking over a child in the crowd cheering his entry into Glasgow; he was arrested and fined five shillings. He had designed the treadles so that they could be adapted to the leg length of various riders. Nevertheless, there is no record of his selling this hobbyhorse (Robertson, 1974).

Another revision of the "running machine" took the form of cranks attached to the front wheel. These cranks were usually pushed by the feet, thus enabling the rider to sit in his carriage without walking in the mud. Several people made this addition, probably independently of one another: for example, Gottlieb Mylius in Themar (Sachsen-Meiningen,

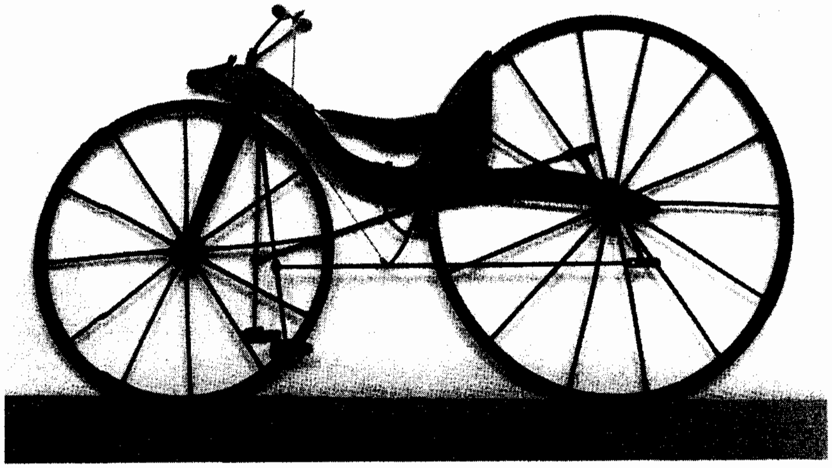

Figure 2.4
Kirckpatrick Macmillan constructed cranks with treadles to drive his "hobby-horse" (1839). The feet still made a walking movement. Photograph courtesy of the Trustees of the Science Museum, London.

Germany) in 1845, Philipp Moritz Fischer in Oberndorf (Germany) in 1853, Joseph Baader in Munich (Germany) in 1862. Lewis Gompertz in Britain constructed cranks for the front wheel that had to be moved by the rider's hands; the "feet in the mud" problem of course remained, but he may still have thought that his feet were needed for balancing (Croon, 1939; Feldhaus, 1914; Klinckowstroem, 1959; Rauck et al., 1979). In the late 1860s, as I will show, several inventors constructed rear-driven velocipedes as well—most of them probably not knowing about MacMillan's hobbyhorse. In summary, the 1860s seem to have been filled with numerous, and widely varying, designs of improved Draisiennes. Only one of them, built by Pierre Michaux, became a commercial success.

In 1861 Michaux, a coach builder in Paris, was asked to repair a Draisienne. One story is that his son Ernest, after testing it, complained about the great effort required to ride the machine and that, subsequently, he and his father designed the front-driven velocipede. The other story is that Pierre Lallement, employed in the Michaux workshop, first constructed such a front-driven Draisienne; he then went to America and left the honor to Michaux. In any case, Michaux continued to improve this velocipede and on 24 April 1868, a French patent was issued to him. The prototypes were made of wood, but by 1866 he had started

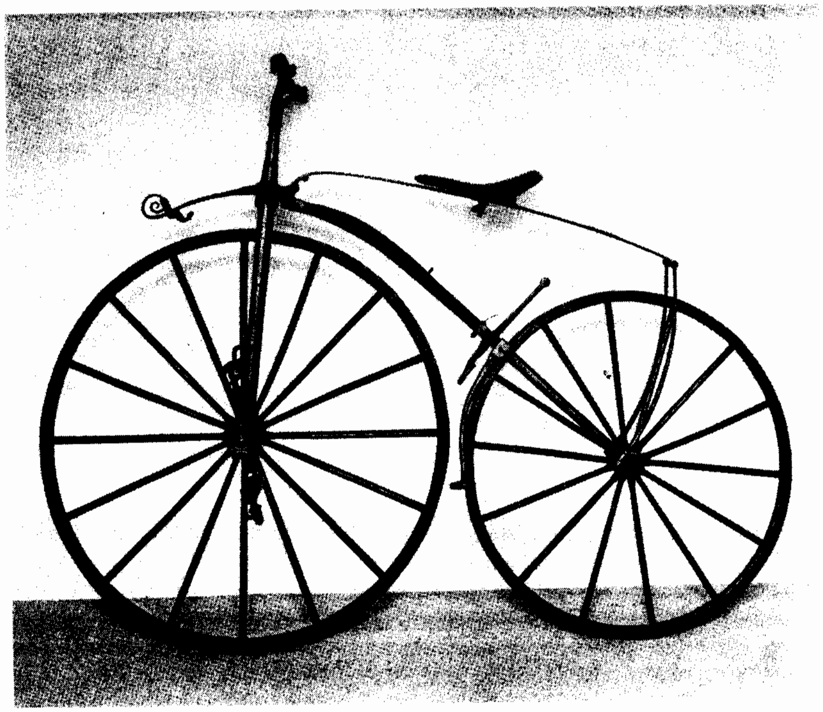

Figure 2.5
The vélocipède constructed by Pierre Michaux in about 1865. Photograph courtesy of the Trustees of the Science Museum, London.

to use iron. His machines were made with front wheels of various diameters (80, 90, and 100 cm) and a smaller rear wheel (see figure 2.5). The cranks had slotted ends so that their radius might be adapted to the length of the rider's legs. The frame was a solid wrought-iron bar with a fork for the rear wheel. A socket at its front end embraced the head of the driving wheel fork, to the top of which the steering handle was fitted. A brake block acting on the rear wheel could be applied by tightening a cord tied around the handlebar. He had also found a solution for the vibration problem: by making the rear wheel smaller, he obtained enough space to position the saddle on a spring brace. The saddle could be moved forward and backward along that spring to adjust to the rider's height. Leg rests were provided for coasting and a step for mounting (Caunter, 1958).

In the meantime, Pierre Lallement had received an American patent on his machine in 1866 and founded a business, but he could not cope with the rapidly increasing competition. The Hanlon brothers, a popular acrobat duo in New York City, were granted a patent on 7 July 1868, in which they suggested the use of rubber rings around the wheels to make them noiseless and to prevent slipping. The Hanlon brothers patented several other small improvements, most of which could be found on the Michaux velocipedes as well. Immediately after the Lallement patent, Americans did not pay much attention to the velocipede, but the Hanlon brothers' activities aroused much interest. December 1868 is identified as the moment at which there began a sudden wild enthusiasm for the Boneshaker, as the velocipede came to be known. Carriage makers commenced to produce the Boneshaker, which became very popular, especially among Harvard and Yale students. Riding schools with such names as "Amphicyclotheatrus" and "Gymnocyclidium" were established. Initially, the Boneshakers were priced at around $125, but soon models could be bought for around $75. The craze died as suddenly as it had started: in August 1869 the machines could be bought for some $12. There was one obvious problem related to the construction of the velocipede: the tendency to push one's body backward and away from the pedals when the going became heavy and more force was needed. The vibration problem also became serious, especially when cities began to pass ordinances against riding on the (smooth) pedestrian walks, thereby condemning the velocipede to the rough road—reminding its users of the origin of the name Boneshaker (Oliver and Berkebile 1974). Lallement returned to France.

In France, Michaux's business was prospering. Already in 1865 his workshop produced 400 velocipedes a year. During the 1867 World's Fair in Paris, he was so effective in promoting his machine that in the months afterward he could not respond in time to all orders he received. The firm decided to deliver velocipedes to the most prominent customers first. This in turn had quite a promotional effect; when the Imperial Prince Louis Napoleon and his friend the Duke of Alba were seen riding Michaux velocipedes, this provided one of the best and surely the cheapest promotion one could imagine. In 1869 the Michaux assembly moved to a new plant, where 500 workers were employed and about 200 velocipedes were produced each day. In England and Germany, the Michaux velocipede was not noticed until about 1867, when it was exhibited at the Paris World's Fair. In 1869 the first English and German designs were marketed. The Franco-German War of 1870–71 halted further development of the velocipede in France and Germany, and the lead was passed to the English (Rauck et al., 1979).

Side slipping, which was not so prominent with the hobbyhorse, was one of the major problems of the velocipede. It is difficult to imagine the skill involved in riding the velocipede: one had to continually adjust one's hold on the handlebar against the tendency of the front wheel to change direction with each thrust on the pedals (Minck, 1968; Woodforde, 1970). Those thrusts, in combination with the turning of the front wheel, made the velocipede frequently subject to side slipping because of its broad, flat, iron-shod wheels.

Before I move on to discuss further developments on the other side of the channel, it is worth noting that only by using commercial criteria can we attribute to Michaux the kind of prominence in the history of the bicycle that he has garnered. Application of either the "who was first" or the "who made the best" criterior would yield different answers. Other inventors were either earlier with their advances or closer to what would later become the bicycle design now considered the "best working machine." Mylius, Fischer, and Baader, who all constructed velocipedes with front-wheel drive, have been mentioned already. More interesting still, several other designs incorporated rear-wheel drive. Because these necessarily involved some mechanical means of transmitting the movement of the feet to the wheel, whether using gears, cranks, or treadles, most of them made it possible to incorporate some "amplification factor" in this movement. This applies to MacMillan's hobbyhorse and to Thomas McCall's similar machine; but also to the machine that was supposedly built in 1869 by André Guilmet and Meyer & Cie. Such an amplification factor would, if fully realized, have made the detour of the high-wheeler unnecessary.

Michaux had continued to modify his velocipede models. The last models, exhibited at the World's Fair, were distinctly lighter and had higher front wheels than the earliest models. The back wheel was kept relatively small. The handlebar was broader to help in controlling the side-to-side movement of the front wheel (Woodforde, 1970). The trend of enlarging the front wheel continued after the center of innovation had moved to England. This trend was further enhanced by the increasing focus on sports and racing as a context for riding the velocipede. One of the first velocipede races was held in May 1868 in St. Cloud, over 1,200 meters. In November 1869 an eighty-three-mile race from Paris to Rouen was held with two hundred participants, including five women. In England the sporting context was further emphasized, which had implications for the design of the bicycle. Because the pedals were fixed to the front wheel without any gearing system, the only way to realize a greater translational speed over the ground while maintaining the same angular velocity of your feet, rotating the wheel, was to increase the diameter of the front wheel. And this is exactly what happened.

At the end of the 1860s, the scene shifted to England completely. The hobbyhorse craze had not lasted, and people had almost forgotten about riding on two wheels when young Rowley Turner brought a Michaux velocipede back to Coventry after visiting the World's Fair in Paris in 1867. Turner, the Paris agent of the Coventry Sewing Machine Cy. Ltd., convinced his uncle Josiah Turner, manager of the company, to accept an order for manufacturing 400 velocipedes for export to France. However, the France-German War of 1870–71 made business with the continent difficult, and the order could not be filled. So, more was needed to get the bicycle industry going. Rowley Turner is reported to have escaped from the besieged city of Paris on his velocipede, after the last train had left (Williamson, 1966: 48). Safely back in England, he was quite energetic in promoting the velocipede, and the sewing machine company trimmed its sails to the new wind. Thus Coventry became one of the centers of the British cycle industry (Grew, 1921; Woodforde, 1970). In the next section I will follow more closely the shaping of this social group of manufacturers.

An important step toward increasing the wheel diameter was the application of wire spokes under tension instead of rigid spokes acting as struts. This enabled the manufacturers to keep the wheels relatively light while making them bigger. This improvement was patented in 1869 by W. F. Reynolds and J. A. Mays in their "Phantom" bicycle (Caunter, 1958). In the same year, the term "bicycle" was introduced in a British patent granted to J. I. Stassen, and thereafter it quickly replaced all other names (Palmer, 1958). In 1870 the bicycle "Ariel" was patented by James Starley and William Hillman (see also figure 2.6). The difference between this vehicle and the Michaux velocipede is striking: where the two wheels of the velocipede were indeed a little different in size, on the Ariel a man was "hurtling through space on one high wheel with another tiny wheel wobbling helplessly behind" (Thompson, 1941: 18). Generally speaking, this was the first lightweight all-metal bicycle, setting the stage for what would become known as the "high-wheeled Ordinary bicycle," or "Ordinary" for short.[6]

2.3 Social Groups and the Development of the Ordinary

The high-wheeled bicycle did not have one unambiguous meaning, but was evaluated in varied ways by different social groups. To describe

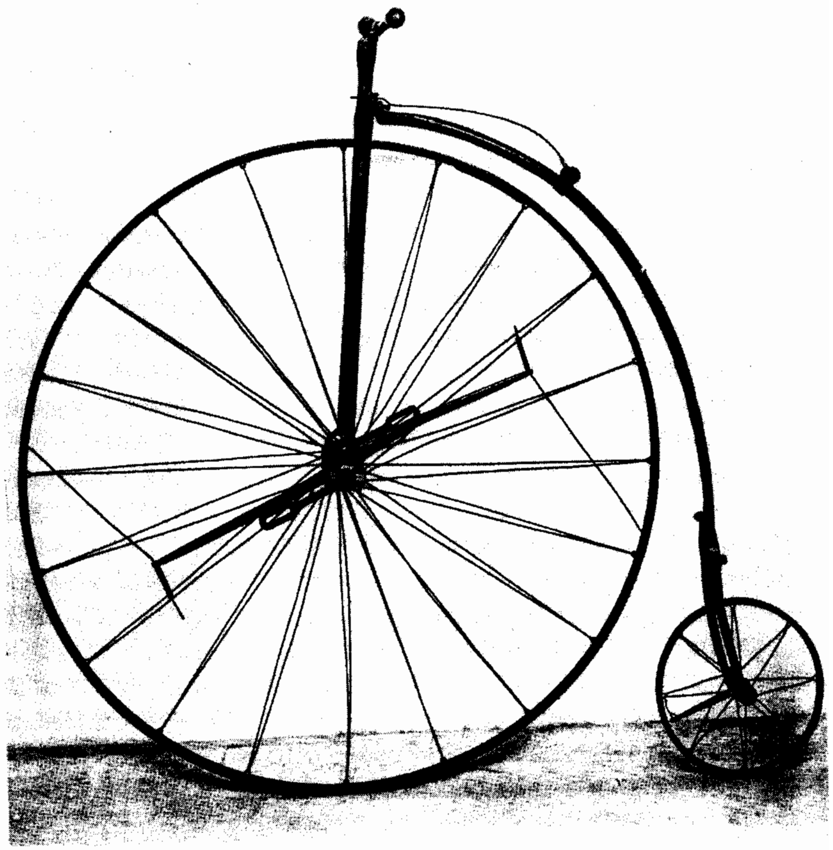

Figure 2.6
The "Ariel," patented in 1870 by J. Starley and W. Hillman, is generally considered to be the first high-wheeled "Ordinary bicycle." The lever to rotate the hub with respect to the rim and thereby increasing the tension of the spokes can be clearly seen. Photograph courtesy of the Trustees of the Science Museum, London.

its development, I will concentrate in this section on the various social groups involved—in its production and use, as well as in criticizing and fighting it. These groups will be described in some detail, and at the same time I will further trace the development of the high-wheeled bicycle. Let us first return to the story of Rowley Turner and the Coventry Sewing Machine Cy. Ltd., and examine the social group of producers.

The Bicycle Producers

The Coventry Sewing Machine Cy. Ltd. changed its name to Coventry Machinists Co., Ltd. in 1869 when it embarked, as Rowley Turner had suggested, on the manufacturing of velocipedes. Such a change of production was quite common in those days, in part because the Franco-German War had a destabilizing effect on British industry. As export opportunities grew scarce, several machine manufacturers started looking for other trades. Weapon makers, sewing machine manufacturers, and agricultural machine producers were only too happy to shift their production to bicycles (see figure 2.7). It is significant that at this stage of velocipede development the machine industry enters the story. Until the late 1860s, the basic skills needed to make a velocipede were those of the carriage builder: working with cast iron, making long bow springs for saddles, bending steel rims, and constructing wooden wheels—this was all well within his trade. But tubular backbones, wire spokes, more sophisticated bearings, special stampings and castings—that was quite another business (Grew, 1921: 27).

Figure 2.7
Not only sewing machine manufacturers but even weapons makers turned to cycle production (part of advertisement reprinted in Grew (1921))

To understand this development better, I will briefly go back in history to sketch the founding of the Coventry Machinists Co. and the role of James Starley, often called in England the "Father of the Cycle Industry." Starley ran away from his Sussex home because he hated farming and wanted to be a mechanical inventor. He was subsequently employed as gardener in a large household. During this period he made several successful contraptions—for example, for use in the garden. One of his more colorful inventions, a "self-rocking basinette," was dropped when the prototype made a young child violently ill by rocking a bit too effectively (Williamson, 1966: 27). Starley repaired watches and clocks in the evening and thus educated himself about the basics of fine machine construction. Then one day he was asked to repair the sewing machine of the lady of the house. At that time a sewing machine was an expensive novelty that not many could afford, and it represented the most complicated mechanism that Starley had ever handled. He took the risk of stripping down the entire machine. He spotted the trouble (a tiny screw had worked loose), reconstructed the machine, and made it run better than ever. This impressed starley's employer so that he persuaded his friend Josiah Turner, manager of the company that was the actual maker of this particular machine, to take on Starley as an employee of the London factory of Nelson, Wilson & Co. (Williamson, 1966: 33).

Turner quickly identified Starley as "a sort of mechanical genius." He helped him to take out a patent on a treadle arrangement that kept the sewing machine running while its operator's hands were free to guide the cloth. By this time Turner had such faith in Starley's technical capabilities that he proposed that they leave the London firm and start a new company together to exploit this invention. They did so, moved to Coventry, and founded the Coventry Sewing Machine Cy. in 1861 (Williamson, 1966: 36–37). Turner recruited other technicians from the London region as well: Thomas Bayliss, William Hillman, and George Singer, to name a few (Grew, 1921: 2; Williamson, 1966: 41). In Coventry they found a receptive atmosphere. To highlight the particular combination of unemployment in technically skilled and unskilled labor, I shall briefly review the economic circumstances of this county.

The Warwickshire city of Coventry was economically and socially in bad shape. The weaving industry had been weakened by a decade of social conflicts between workers and employers. The long conflict, instigated partly by the tariff policies of the national government and partly be class struggle, almost ruined the ribbon weaving industry. Of the original eighty weaving masters existing befare 1855, only twenty remained by 1865; there had been at least fifty bankruptcies. Unemployment was very high in Coventry. Poverty spread, and so many families were threatened by starvation that a national appeal was launched in the early 1860s (Williamson, 1966: 38–40). From the census reports of 1861 and 1871, a remarkable decrease of the population of Coventry can be traced, especially when these figures are seen in the perspective of the population growth in other towns in the Midlands.[7] The watchmaking industry, which had been expanding between 1830 and 1860, had declined as well, although for other reasons. Coventry watchmakers did not have factories, and the individual masters in their isolated workshops were not able to compete with the cheaper machine-produced products imported from America and Switzerland (Williamson, 1966: 40). Despite the displacement of people from Coventry, the new sewing machine company still found many skilled workers. For Coventry this meant the beginning of its development into an engineering city. The watch trade provided the nucleus of skilled labor, and the ribbon trade the pool of unskilled labor, with which Coventry would graduate from the sewing machine and the bicycle to the motor bicycle and the motorcar, climbing back toward prosperity as the nineteenth century drew to a close (Prest, 1960: x).

The Coventry Sewing Machine Cy. prospered to such an extent that larger premises were necessary after seven years. The company had continuously improved its sewing machines by adding innovations and turning out new models with names such as "The European," "Godiva," "Express," and "Swiftsure." When Rowley Turner convinced his uncle Josiah to start making velocipedes, the new product was approached in the same innovative spirit (Williamson, 1966: 41). Starley's immediate reaction when confronted with the new machine was to lift the velocipede and criticize it for being weighty and cumbersome (Williamson, 1966: 48). Starley learned to ride the machine, however, and he quickly thought of a series of small but important modifications. For example, he fitted a small step to the hub of the rear wheel to enable the rider to simply step on. The usual way of mounting a velocipede was to take a short run and leap into the saddle. Some of these modifications probably have been incorporated in the first velocipedes produced by the Coventry Machinists Co., but there are no records of these early products.

Starley and Hillman then concentrated on designing a new, light velocipede. As sewing machine constructors rather than carriage builders, they employed quite different techniques than had Michaux. For one thing, there were no wooden parts on their machine. They followed Reynolds and Mays by using wire spokes under tension to make the wheels without heavy struts (made of wood or, later, hollow steel tubes) loaded by pressure forces. But added to this was a mechanism to tighten these radially positioned spokes and thus stiffen the wheels, which in Reynolds's and Mays's case still lacked rigidity. This was done by fixing two levers to the middle of the hub; the levers were connected by wires to opposite positions on the rim. By tightening these wires, one could make the rim turn relative to the hub until the spokes had the required tension (Caunter, 1958: 6). Finally, they followed the trend of enlarging the front wheel. Thus Starley and Hillman patented the Ariel on 11 August 1870 (see figure 2.6). They had such a confidence in their new product that they left the Coventry Machinists Co. and started a new business (Williamson, 1966: 49). Almost at the same time, W. H. J. Grout took out a patent on his "Grout Tension Bicycle" (Grout, 1870). This patent added some further basic elements to the scheme of a high-wheeled bicycle, notably the hollow front fork that further reduced the frame's weight, massive rubber tires, and a new means of mounting the spokes. Grout's radial spokes were threaded into nipples loosely riveted into the rim, which could be used to adjust the tension of the spokes and thus to true the wheel by screwing them on and off the spokes. These two patents can be said to have laid the basic pattern of the high-wheeled bicycle in the early 1870s.

Of course Turner, Starley, and the other Coventry Machinists Co. men were not alone in identifying the velocipede as an attractive new line of manufacture. The city of Coventry soon saw a variety of former watchmakers, ships' engineers, cutlery shop workers, and gun makers starting small workshops in which to build velocipedes.[8] In other towns, such as Leicester and Liverpool, velocipede makers were commencing business as well. Coventry was not a manufacturing town, however, as was Birmingham; thus in search of suitable materials, the Coventry engineers had to turn elsewhere. For example, Sheffield provided bar steel for bearings and wire for spokes; Walsall supplied saddles; springs came from Redditch and Sheffield; Birmingham firms provided the drawn steel tubes crucial to making those light metal frames, and it supplied the steel balls for bearings (Grew, 1921: 27). The assistance of Birmingham was not without risk for Coventry. Although at first the firms in Birmingham produced only half-finished materials and velocipede parts, they started to look around for outlets for their production in slack times.

For example, Perry & Co., pen makers, and the Birmingham Small Arms Co. (B.S.A.) began to supply sets of fittings and parts for small workshops, which were in this way able to build velocipedes without requiring the more expensive tools and machinery (Grew, 1921: 29–30). However, making good parts is not the same as making good bicycles, and Coventry remained the center of the British cycle industry for a long time. In the 1870s and 1880s the industry spread all over the Midlands, Yorkshire, and part of London.

Starley and Hillman did not immediately market their Ariel, but first produced and sold velocipedes in which they incorporated many of Starley's improvements. Hillman suggested that the launching of the high-wheeled bicycle had to be marked by a spectacular promotional feat. They decided to set up a kind of unusual test: completing the ride from London to Coventry in one day. And they did, probably in 1871.[9] Both gentlemen took their bicycles to Euston Station on the train, spent the night in the station hotel and got up before daylight. They had a light breakfast and started out along the cobbled roads of London. Once outside the city the roads became better, and at about 8:30 A.M. they reached St. Albans, where they stopped to have an ample breakfast. The next stretch ran over the Chiltern Hills. On some of the steeper hills they had to walk, but compensation came on the long downhill portions where speeds of some twelve miles an hour were attained. "Disaster might have overtaken the gentlemen who wished to take full advantage of the hills, had it not been for Mr. Starley's ingenious brake." By one o'clock the riders had covered about half the distance, and they enjoyed dinner and an hour of rest near Bletchley. Mounted again, they were cheered or by the inhabitants of towns and villages, few of whom had seen a bicycle before. Only one mishap befell them. "Mr. Hillman was thrown from his machine when the rubber tyre of his front wheel came off but escaped with nothing worse than a grazed hand. He was able to bind the tyre on again and proceed without further trouble." The last miles from Daventry to Coventry were hard. The men were tired and the darkness made it difficult to avoid stones and holes in the road. But just when the clock of St. Michael's struck midnight, it is said, they reached Starley's residence in Coventry. The ninety-six miles had been completed within one day and with the bicycles still in almost perfect condition. The contemporary account finishes by stating that "the bicycle that has been developed by Messrs. Starley and Hillman from the velocipede is a most efficient form of human transport. It may be recorded that the two intrepid gentlemen, though tired, and stiff after their long ride, were no worse for their adventure." However, an intimate footnote was added in the margin of this account that for both riders the experience was painful enough to oblige them to remain in their beds "for two or three days." When, subsequently, the Ariel was marketed in September 1871, it was priced at £8 (Williamson, 1966: 54).

So they were quite active, these bicycle producers. But for whom were they producing? For whom was the Ariel's spectacular promotion intended? The demand increased. By the end of the 1870s clubs and associations for cyclists had been established in most countries. To continue the story of the high-wheeled Ordinary bicycle, we will now shift our focus to its users.

The Ordinary Users

The memorable ride of Starley and Hillman enhanced the image of the new high-wheeled bicycle as a sport machine, and records were set and contested on all classic roads of England. For example, the Brighton Road is associated with the earliest bicycle performances, as is Watling Street, on which Starley and Hillman crossed the Chiltern Hills. Especially on the Brighton Road, relay rides were often held against the four-horse coach (Grew, 1921: 78). Track racing started soon as well. Probably the first was in 1869 in Crystal Palace, London (Woodforde, 1970: 161), but other tracks sprang up in Birmingham, Wolverhampton, and Leicester (Grew, 1921: 67–68). After the Franco-German War, racing on Ordinaries began on the continent as well.[10] Because the German local ordinances were rather limiting—for example, restricting racing on public roads to the early morning and late evening hours—in Germany the bicycle clubs started to build separate racing courses.[11] We will come back to bicycle racing below, for often there was more at stake than just a medal and a small cash prize.

Whereas skiing began as a way of getting about and evolved into a sport, bicycling began as a sport activity and evolved into a means of transport. Even when the rider of a high-wheeled bicycle was not actually racing, he viewed his activity primarily as an athletic pastime. It was not easy to mount the high-wheeled bicycle, even with the provision of a step directly above the trail wheel. Uwe Timm (1984: 17–22) gives a convincing and colorful description of his uncle Franz Schröder's efforts to learn how to ride high-wheeled bicycle: "Schröder experienced this afternoon the large and fundamental difference between theory and practice. He mounted and fell down. The crowd of spectators was standing there and kept silent. He stood up again and fell off again."[12] He repeated this motion several times, to increasingly enthusiastic clapping and cheering: "Hopf, hopf, hopf, immer aufem Kopf!"[13] By the end of the afternoon he had learned how to mount and ride in a straight line; making a curve and dismounting were not yet in his repertoire, so each little ride ended in a fall. However, after another week of trying (in which he lost two finger tips between the spokes of the front wheel), he had mastered the art of riding a high-wheeled bicycle. No wonder bicyclists wore an anxious air. "Bicyclist's face," this expression was called, and newspapers predicted a generation with hunchbacks and tortured faces as a result of the bicycle craze (Thompson, 1941: 18). Going head-over-heels was quite common, as we will see shortly. Partly for that reason, and because there was no freewheel mechanism—which implied that the cranks were permanently turning around when riding—a special mode of riding was practiced when moving downhill. This "coasting" again required some athletic ability: when the bicycle was moving fast, the legs were thrown over the handlebar to the front (see figure 2.8).

Learning to ride a bicycle became a serious business in the 1870s. In some European cities, bicyclists had to pass an examination to prove their proficiency (Woodforde, 1970: 120). Bicycle schools existed in most towns of some importance. Partly this was made necessary by the maturity of the riders, none of whom had learned cycling as a child, which is now the usual way, at least in bicycling countries.[14] On the other hand, the bicycles of those days were definitely more difficult to ride than are modern versions. Even walking a bicycle could result in a bruised leg when the novice had not yet learned how to keep free of the revolving pedals.

Charles Spencer, owner of the London gymnasium bicycling school, described in his instruction book how to mount a high-wheeled Ordinary:

> Hold the handle with the left hand and place the other on the seat. Now take a few running steps, and when the right foot is on the ground give a hop with that foot, and at the same time place the left foot on the step, throwing your right leg over on to the seat. Nothing but a good running hop will give you time to adjust your toe on the step as it is moving. It requires, I need not say, a certain amount of strength and agility.[15]

The cycling schools and instruction books tried to make the art of bicycling as explicit as possible. For example, what

> each learner must remember is simply to turn the handles in the direction in which he is falling. Having drummed this into his head, the rest is easy. He will soon discover that there is a happy medium and that the bars require only to be turned slightly, and instantly brought back to the straight as soon as the machine has resumed the perpendicular.[16]

It is unlikely that a modern bicyclist would be able to describe so adequately what exactly she is doing when keeping her balance. Her craft of riding a bicycle is almost completely "tacit knowledge." However, riding the high-wheeler could be just as pleasant and comfortable as it was dangerous. Having mounted an ordinary bicycle—by this time implicitly meaning a high-wheeler—one would immediately feel its easy-rolling, billowy motion as very different from the bone-shaking effect of the velocipede.[17] Moreover, the pedals almost directly beneath the saddle

Figure 2.8
The first rider has thrown his legs over the handlebar when coasting downhill.

enabled one to sit comfortably upright, with the bar in one's lap; on the velocipede, there had always been the pushing forward of the legs and the pulling on the handlebar to compensate for that pushing. There was a direct advantage of being so high above the ground: the roads had worsened since the railways eclipsed the horse coach, and the large wheel could keep its rider well above the water-filled holes and mud, while dealing effectively with the bumps.

Few men over middle age, and even fewer women, attempted to ride the high-wheeled bicycle. The typical bicyclist—by this time meaning an Ordinary rider—had to be young, athletic, and well-to-do. Accordingly, bicycling still had, as in the early days of the hobbyhorse, an element of showing off:

> Bicycle riding, like skating, combines the pleasure of personal display with the luxury of swift motion through the air. The pursuit admits, too, of ostentation, as the machine can be adorned with almost any degree of visible luxury; and differences of price, and, so to speak, of caste in the vehicle, can be made as apparent as in a carriage. It is not wonderful, therefore, that idle men sprang to the idea.[18]

Generally, bicycling was associated with progress and modern times. This was sometimes voiced in grandiose terms:

> The bicycle: the awakening of a new era. The town comes into the village, the village comes into the town, the separation comes to an end, town and village merge more and more. Cyclisation: the era of the bicycle, that is the new time with richer, broader and more mobile civilisation, a back to nature which however keeps all advantages of culture.[19]

But cycling was also linked with new social movements in more concrete ways. The first meeting of the bicycle society of the town of Coburg was observed by a local police officer, who had to ensure that this society was not an undercover meeting of the forbidden social democratic party. Schröder's wife Anna was pointed out for committing subversive actions that were intuitively understood as revolutionary and the first exemplification of the women's movement in Coburg. "*Petroleuse* on a high-wheeler" read the headline in the local newspaper, thus associating female bicyclists with *petroleuses* of the 1871 *Commune.*[20] And especially in the days of the low-wheeler, after the high-wheeled bicycle had become obsolete, cycling was explicitly linked to feminism. I shall return to this point. For an instrument of the liberation of the proletariat, the bicycle was too expensive. The laborer who would have liked to use the machine for his transportation to work could not afford one, until a second-hand market had developed.[21] Indeed, many workers were still riding their high-wheeler after 1900; by that time it had been nicknamed "Penny-farthing" because it was not "ordinary" any more. In Ashford, Kent, a gas lamp lighter still used it in 1914, finding it useful in his work (Woodforde, 1970: 49).

The Nonusers of the Ordinary

With only the group of "young men of means and nerve" riding the Ordinary, there were many more people not using it. Some of them wanted to ride a bicycle but could not afford one, or were not physically able to mount the high-wheeler, while others actively opposed the machine.

There were several reasons for the antagonism against bicyclists. One was irritation caused by the evident satisfaction with which the riders of the high-wheeler elevated themselves above their fellow citizens. This irritation gave rise to derisive cheers such as "Monkey on a gridiron!" (Wells, 1896: 24) or the loudly hailed pronouncement that "your wheel is going round!" (Woodforde, 1970: 50). Jokes like this inflicted no injury, "but when to words are added deeds, and stones are thrown, sticks thrust into the wheels, or caps hurled into the machinery, the picture has a different aspect."[22] The touring clergyman who made this observation added, "All the above in certain districts are of common occurrence, and have all happened to me, especially when passing through a village just after school is closed. The playful children just let loose from school are generally at this time in an excitable state of mind."[23]

Another reason for the antagonism was the threat posed by the bicyclists to those who were walking.

> Pedestrians backed almost into the hedges when they met one of them, for was there not almost every week in the Sunday newspaper the story of some one being knocked down and killed by a bicycle, and letters from readers saying cyclists ought not to be allowed to use the roads, which, as everybody knew, were provided for people to walk on or to drive on behind horses. "Bicyclists ought to have roads to themselves, like railway trains" was the general opinion. (Thompson, 1941: 18)

Police and magistrates supported this view. Local ordinances posed various restrictions on bicycling, often widely different in different towns. A German cantonal judge observed that these local ordinances stipulated many obligations for the cyclists, but hardly any rights.[24] Elaborating on these rights, he remarked that the offense bicyclists suffered from most frequently was defamation. Carriage drivers being overtaken by a bicycle, pedestrians having to wait a few seconds before crossing a street—

they all would shout insults at the cyclist. The judge described the various forms of defamation recognized in German law and added that the so-called *einfache Beleidigung* (simple slander), which could be exerted by words, gestures, or pawing, was most common. An enthusiastic bicyclist himself, he used to write down all insulting words shouted at him; he was amazed by the public's creativity. Newspaper reports about fights between bicyclists and pedestrians or coach drivers were quite common. A particularly flagrant attack, Woodforde reports, happened on 26 August 1876, when a coach driver lashed an overtaking bicyclist with his whip and the coach guard actually threw an iron ball, which he had secured to a rope, between the spokes of the wheel (Woodforde, 1970: 52). An offense with which bicyclists were frequently charged was "riding furiously," especially on roads with excellent wood paving such as the high road between Kensington and Hammersmith in London. The antagonism of the general public can be sensed through the following excerpt from a court hearing transcript, concerning four men charged with furious riding: "Police constable ZYX 4002 deposed that he was on duty the previous evening, and saw the defendants riding at a rate of forty miles an hour; he walked after them and overtook them ... taking them to the station handcuffed."[25] If we can assume that this speed of forty miles an hour was a gross overstatement, the acceptance of such a statement suggests a generally negative opinion about bicycling in those days.

There were also people who wanted to ride a bicycle but could not do so. One reason has been mentioned already: the price of the Ordinaries prevented middle-class and working-class people from buying a new machine. The other main reason was the problem of safety. This problem made older men and women reluctant to mount the high-wheeler. For women there was an additional problem, and I will turn to that first.

In 1900 it was still possible to find newspaper articles such as the following, reporting on the observation of a two-seater bicycle with a man and woman on it:

> The numerous public that was walking in the Maximilian-strasse, yesterday at noon, witnessed an irritating spectacle that gave rise to much indignation.... Unashamed, proud like an Amazon, the graceful lady displayed herself to men's eyes. We ask: Is this the newest form of bicycle sport? Is it possible that in this manner common decency is being hit in the face without punishment? Finally: is this the newest form of advertising for certain female persons? Where is the police?[26]

This must have been a rather exceptional outcry in 1900, especially as it concerned merely a low-wheeled two-seater. But it makes one think about the sentiments expressed two decades earlier against women wanting or actually trying to ride on high-wheeled bicycles. The whole weight of Victorian prudery set itself against women taking such a masculine and, on the high-wheeler, revealing posture.[27] Some bicycle producers tried to find a solution for what was euphemistically called "the dress problem." In 1874 Starley and Hillman pursued the idea of S. W. Thomas, patented in 1870, of having two pedals on one side of the velocipede, thus enabling it to be "side-ridden."[28] This is what Starley and Hillman did with their successful Ariel high-wheeler. The rider sat in a sidesaddle position, the handlebars being shortened on one side and lengthened on the other. The rear wheel was mounted on an overhung axle, and the front wheel was offset from the track of the rear wheel to counteract the bias of the sidesaddle posture (see figure 2.9). It all seems rather complicated, and the machine must have been quite difficult to master. This technical solution to the dress problem did not become a success, and few sidesaddle bicycles were sold.

However, solutions other than purely technical innovations were tried—and indeed, were more successful. First, Victorian morals could occasionally be a little more flexible than one might assume. For example, a young lady who wrote to a magazine in 1885 about having used a bicycle (which at that date must have been a high-wheeled Ordinary) was reassured in the reply: "The mere act of riding a bicycle is not in itself sinful, and if it is the only means of reaching the church on a Sunday, it may be excusable."[29] Another solution to the dress problem posed by the Ordinary was to modify the designs of women clothing and, accordingly, to set new standards of fashion. A third way for women to ride cycles while avoiding the Ordinary was to use tricycles.

The "safety problem" was pressing for many nonusers of the Ordinary. As mentioned, the Ordinary rider was liable to go head over heels when encountering a small obstacle like a stone, a hole in the road, or an animal wandering about. The trend of enlarging the front wheel of the velocipede had continued once speed had become so important, and this made it necessary to move the saddle forward in order to keep pedals within reach of the feet. This implied a reduction of the rear wheel's diameter—partly because otherwise the machine could not be mounted at all, partly to reduce the bicycle is weight, and partly for aesthetic reasons (it set off the grandeur of the high wheel). But these two developments moved the center of gravity of the bicycle and rider far forward, to

Figure 2.9
The ladies' model "Ariel" (to the right), designed in 1874 by J. Starley and W. Hillman. The pedals do not drive the cranks directly, but are placed at the ends of levers, pivoted some distance in front of and slightly above the front wheel axle on the left side of the bicycle. About halfway along these levers, short connecting-rods communicate the motion of the pedals to the overhung crank-shaft. The axle forming the pivot for the pedal levers is supported on the inside by an arm attached to the front fork and on the outside by a stay that joins the lower crosspiece of the steering head.

The lever to rotate the hub with respect to the rim and thereby increasing the tension of the spokes can also be seen in both bicycles. Photograph courtesy of the Trustees of the Science Museum, London.

a position almost directly above the turning point of the system. Thus only a very small counter force—for example, from the bumpiness of the road, but also from the sudden application of the brake—would topple the whole thing. Another serious and frequent cause of falls was getting a foot caught between the spokes, for example when feeling for the step before dismounting. Different ways of falling forward even got their own labels (as in present-day wind surfing), so that an experienced Ordinary rider remarked, "The manoeuvre is so common, that the peculiar form of tumble that ensues is known by the distinctive name of 'the cropper' or 'Imperial crowner.'"[30] Falls were such an accepted part of bicycling that producers advertised their bicycles' ability to withstand falls, rather than claiming that they did not fall at all. In the *Humber Bicycle Catalogue* of 1873, a letter from a customer is reproduced, saying that although his Humber bicycle "on several occasions [had] been engaged in universal spills and collisions, it is now almost as sound as when first despatched from your works."[31] This, however, was to change within a few years, when manufacturers began to regard women and older men as potential bicycle buyers.

2.4 Relevant Social Groups

In this section, the flow of the historical case study is halted for the first methodological intermezzo. The concept "relevant social group" will be introduced.

I have described the development of the Ordinary bicycle by tracing what various groups thought of it. I used these perspectives to avoid the pitfall of retrospective distortion. If we are to find out how the so-called detour of the high-wheeled bicycle came about, it seems wise to stick as closely as possible to the relevant actors, rather than bringing our own evaluations to bear on the story. Thus we may be able to show that what in a Whiggish account of bicycle history seemed a strange and ineffective detour was indeed quite straightforward when viewed from the actors' perspective. ("Whiggish" is an account that presents history as uninterrupted progress, implying that the present state of affairs follows necessarily from the previous.)

But there is another reason to focus on social groups than merely the desire to avoid retrospective distortion. One of the central claims in this book will be that such social groups are relevant for understanding the development of technology. I will first show how empirical research can identify the social groups that are *relevant for the actors.* Then I will argue that these social groups are also theoretically *relevant for the analyst* when he or she sets out to explain the development of technical change.

Empirical Research to Identify Relevant Social Groups

Relevant social groups may be identified and described by following two rules: "roll a snowball" and "follow the actors." The snowball method is used in contemporaneous sociological research, and I will use a study of a scientific controversy to illustrate this method.[32] Typically one starts by interviewing a limited number of actors (identified by reading the relevant literature) and asks them, at the end of each interview, who else should be interviewed to get a complete picture. In doing this with each interviewee, the number of new actors at first increases rapidly like a snowball, but after some time no new names will be mentioned—you have the complete set of actors involved in the controversy.[33] This is a neat methodological solution to the problem of how to delineate the group involved in a scientific controversy, at least when interviewing is a possible technique.

The same method is applicable in historical research. Just as we can find relevant actor by noting who is mentioned by other actors, we can identify what social groups are relevant with respect to a specific artifact by noting all social groups mentioned in relation to that artifact in historical documents (see figure 2.10). When after some time the researcher does not find reference to new groups, it is clear that all relevant social groups have been identified.

By using the snowball technique, a first list of relevant social groups can be made. Using this as a starting point, the researcher can then "follow the actors" to learn about the relevant social groups in more detail.[34] This can be quite a straightforward process: because these social groups are relevant for the actors themselves, they typically have described and delineated the groups adequately. Thus marketing people will identify user groups and describe them as far as is relevant; producers thus had identified rich, young, athletic men as bicyclists; and anticyclists had identified tricyclists and bicyclists. Thus after the first step of identifying the relevant social group, two subsequent steps were taken: a second to describe the relevant social groups in more detail, and a third to further identify the relevant social group by delineating it from other relevant social groups. In practice, these description steps are of course interdependent, and it is not practical to carry them out completely separately.

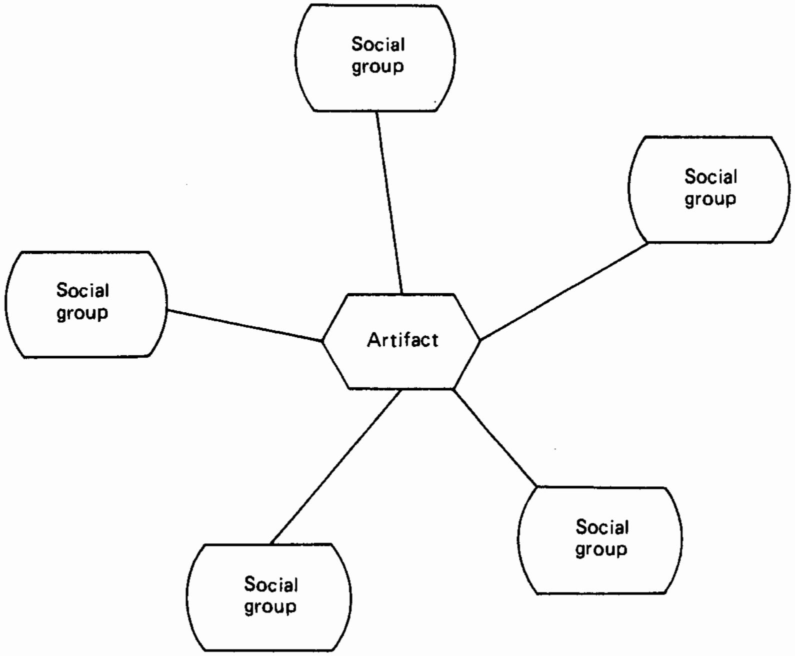

Figure 2.10
Related to an artifact, the relevant social groups are identified.

For example, the relevant social group of Ordinary users was characterized, in the first descriptive step, as being constituted of people who saw the Ordinary as a sporting machine that was rather hazardous to ride. In the second step this relevant social group was further described as consisting of young athletic men, distinctly upper and upper-middle class. A brief reference to road maintenance in the new railway era hinted at the wider socioeconomic context. The description of relevant social groups is as important as the detailed description of artifacts in standard technical histories. So I will, when turning to a discussion of tricycles, devote substantial space to women, postmen, and queens as well as to differential gears, big wheels, and brakes.

Then, for the third step, the relevant social groups' boundaries, intuitively assumed at the outset, are traced more precisely. Again, the actors can be followed. In the turmoil of technical development actors, to make sense of their world, will identify new relevant social groups or forget about others. Thus the boundaries of social groups, although once clear-cut, may become fuzzy; new groups may split off and old groups may merge into new ones. Actors thus "simplify" and reorder their world by forgetting about obsolete distinctions or by drawing new boundaries.[35] As I will show, at some point bicycle producers concluded, for example, that within the relevant social group of nonusers, women should be separated out as an important relevant social group. Similarly, the relevant social group of Ordinary users did not remain unchanged. At first it coincided completely with the group of cyclists. With the coming of the low-wheeled bicycle, some parts of the relevant social group of nonusers became users of the safety bicycle, and the relevant social group of Ordinary users changed accordingly. Its boundaries changed—some categories of cyclists switched from the high-wheeler to the safety. But its key characteristics changed as well: in the beginning its members could be labeled "young men of means and nerve," and Franz Schröder, a typical Ordinary rider, successively passed through the stages of being associated with social democracy and other "revolutionary" movements to being simply the laughingstock of town.

Relevant Social Groups: Also Relevant for the Analyst

The concept of "relevant social group" is an actor's category. Although actors generally do not use these words, they actively employ the concept to order their world. A crucial claim in the development of a social constructivist model of technology is, however, that "relevant social group" is also an important analyst's category. It will help us to describe the development of technical artifacts in terms that meet the requirements set out in the first chapter.

Technological development should be viewed as a social process, not an autonomous occurrence. In other words, relevant social groups will be the carriers of that process. Hence the world as it exists for these relevant social groups is a good place for the analyst to begin his or her research. Thus the analyst would be content to use "cyclists" as a relevant social group, but introduce separate "bicyclists" and "tricyclists" only when the actors themselves do so. The basic rationale for this strategy is that only when a social group is explicitly on the map somewhere does it make sense for the analyst to take it into account.

There seems to be one obvious problem with this argument, which has two important aspects, the political and the epistemological. The political aspect arises out of recognition that powerless social groups—those that do not have the ability to speak up and let themselves be found by the analyst—will thus be missing in the account. The epistemological aspect of the problem concerns the suggested identity between actors' and analysts' categories. The first formulation of the problem is relevant for the practical and political relevance of technology studies, to which I will return in the last chapter. The second formulation addresses a classic debate in the philosophy of the social sciences. This problem, however, does not need to exist, in either of the two formulations.

The problem of the "missing groups" does not exist if the conceptual framework I am developing is taken in the right spirit—as a collection of sensitizing concepts that aims to provide the researcher with a set of heuristics with which to study technological development. Another slightly rhetorical way of making the same point is to emphasize that the goal is to develop a framework for *scientific research*, not a computer program for an expert system to carry out social studies of technology. Let me give one example, comparing my treatment of the bicycle and the fluorescent lamp case studies. In the bicycle case I followed the lead of the actors and included the relevant social group of women in my description. In the fluorescent lamp case I did not, as will become clear in the fourth chapter. An expert system would have done so, however, because a General Electric manager once mentioned "the housewife" as a relevant social group. Another human researcher might have decided differently, and have included the relevant social group of housewives in her description—there is no way of deciding "mechanically" which of the two accounts would be best. This is where the approach outlined in this book draws most heavily on methods of interpretative research.

Similarly, no simple identity between actors' and researchers' categories is advocated. I am proposing the combined method of "snowballing" and "following the actors" as heuristics—a negative heuristic to avoid a facile projection of the analyst's own categories, which might lead to retrospective distortion and Whiggish accounts; and a positive heuristic to help identify relevant social group that do not figure in the standard histories of the specific technology. In the next chapter some concepts will be introduced that are exclusively analysts' categories.

What I have been arguing here about the identification, delineation, and description of relevant social groups also applies to the characterization of artifacts. If we want to understand the development of technology as a social process, it is crucial to take the artifacts as they are viewed by the relevant social groups. If we do otherwise, the technology again takes on an autonomous life of its own. Thus in this descriptive model the meanings attributed to the artifact by the different relevant social groups constitute the artifact. I described, for example, the artifact Ordinary bicycle "through the eyes" of members of the relevant social groups of women, older men, and Ordinary users. The definition of the Ordinary as a hazardous bicycle (for the relevant social groups of women and elderly men) was supplemented by listing specific ways of using the artifact, such as track and road racing, touring, and showing off in parks (for the Ordinary users). The risky aspects of riding the Ordinary were explicated by describing in some detail the techniques involved in mounting the machine and in coasting downhill. Also the pleasure and comfort of riding the Ordinary were described and contrasted with the bone-shaking experience of riding bicycles with smaller wheels.

As an aid in describing the meanings attributed by the relevant social groups to an artifact, I will now focus on the problems and solutions as seen by these relevant social groups.

2.5 *Focus on Problems and Solutions*

When my daughters want to find out about a ball, they do not sit down and stare at it. They pick it up, throw it against the wall, kick it, or play catch. When a physicist wants to study an atom, she excites it and studies the emission spectrum when electrons fall back into their lower energy states. When you want to study a social system—for example, the relationship of a married couple—not much would be learned by looking at it in steady state. Rather, it would help if you could induce a change—for example, by sending in a newborn child. Then insight might be gained about the hidden properties and processes that keep the social system together, or not.[36] This principle of focusing on disturbances when studying a system can be usefully employed when describing the meanings attributed by relevant social groups to an artifact.

Therefore in describing the artifacts I have tried to avoid the uninformative states of equilibrium and stability. Instead the focus was on the problems as seen by the various relevant social groups (see figure 2.11). Linked to each perceived problem is a smaller or larger set of possible solutions (see figure 2.12).

What kind of model is emerging? First, focusing on the different relevant social groups seems to be an effective way of guarding against the kind of implicit assumptions of linearity that I have criticized in the first chapter. From a traditional, quasi-linear view, the bicycle's history was depicted as a simple genealogy extending from Boneshaker to velocipede to high-wheeled Ordinary to Lawson's Bicyclette, the last labeled "the first modern bicycle" (see figure 1.3). All other bicycles were pushed to the margins of history because they are, retrospectively, seen to have failed. If, on the contrary, the various alternatives to the Ordinary are initially[37] put on an equal footing and considered as variants from which the next stable artifact had to be selected (as in figure 1.4), this view could be helpful in avoiding an implicit assumption of linearity.

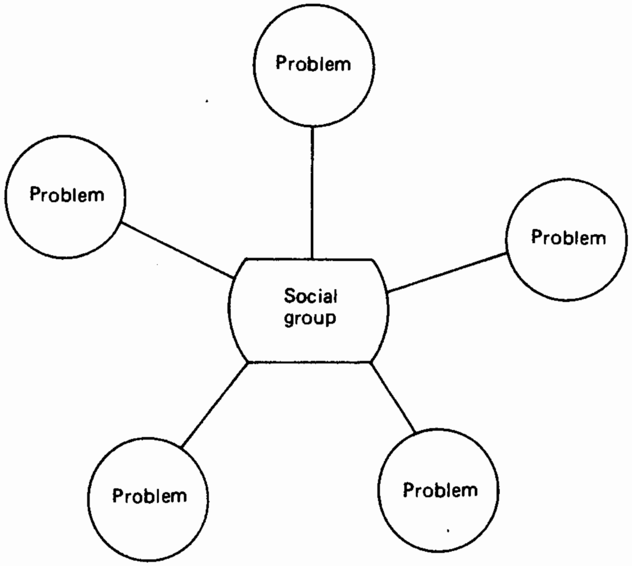

Figure 2.11
Artifacts are described by focusing on the problems perceived by the relevant social groups.

Second, parts of the descriptive model can effectively be cast in evolutionary terms. A variety of problems are seen by the relevant social groups; some of these problems are selected for further attention; a variety of solutions are then generated; some of these solutions are selected and yield new artifacts. Such an evolutionary representation would thus not exclusively deal with artifacts, but would consist of three layers: variation and selection of (1) problems, (2) solutions, and (3) the resulting artifacts. Thus the results of variation and selection on the level of problems is fed into a further evolutionary process of variation and selection of solutions, which subsequently generate the artifacts (see figure 2.13).

One could try to summarize the narrative of the case study in one enormous drawing, compiling artifacts, relevant social groups, problems,

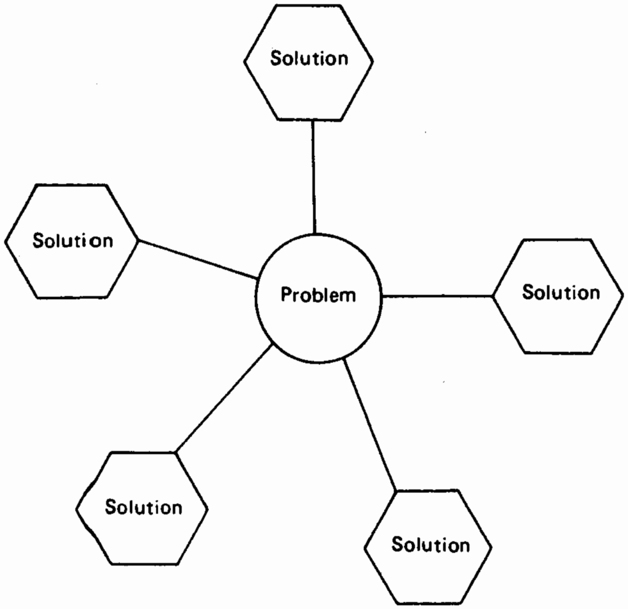

Figure 2.12
Finally, the solutions are described that are seen as available to each of the perceived problems.

solutions, and the subsequently modified artifacts. There are, however, two related problems lurking behind such an evolutionary representation. The first is practical and becomes obvious should the reader accept the challenge and try to make such a drawing of the case study presented in this chapter—it simply cannot be done because of the immense complexity. The other problem is that, if such a multilayered representation of problems/solutions/artifacts is not completely adequate, one almost inevitably ends up with the assumption that an artifact is a constant, fixed entity—to be generated in the variation process and then ushered through the selection processes.[38] In the remainder of this chapter we will find that this is not the case. Rather, an artifact has a fluid and ever-changing character. Each problem and each solution, as soon as they are perceived by a relevant social group, changes the artifact's meaning, whether the solution is implemented or not.

In the next section the history of the bicycle is followed further, with a focus on the solutions that various relevant social groups saw to the safety problem of the Ordinary.

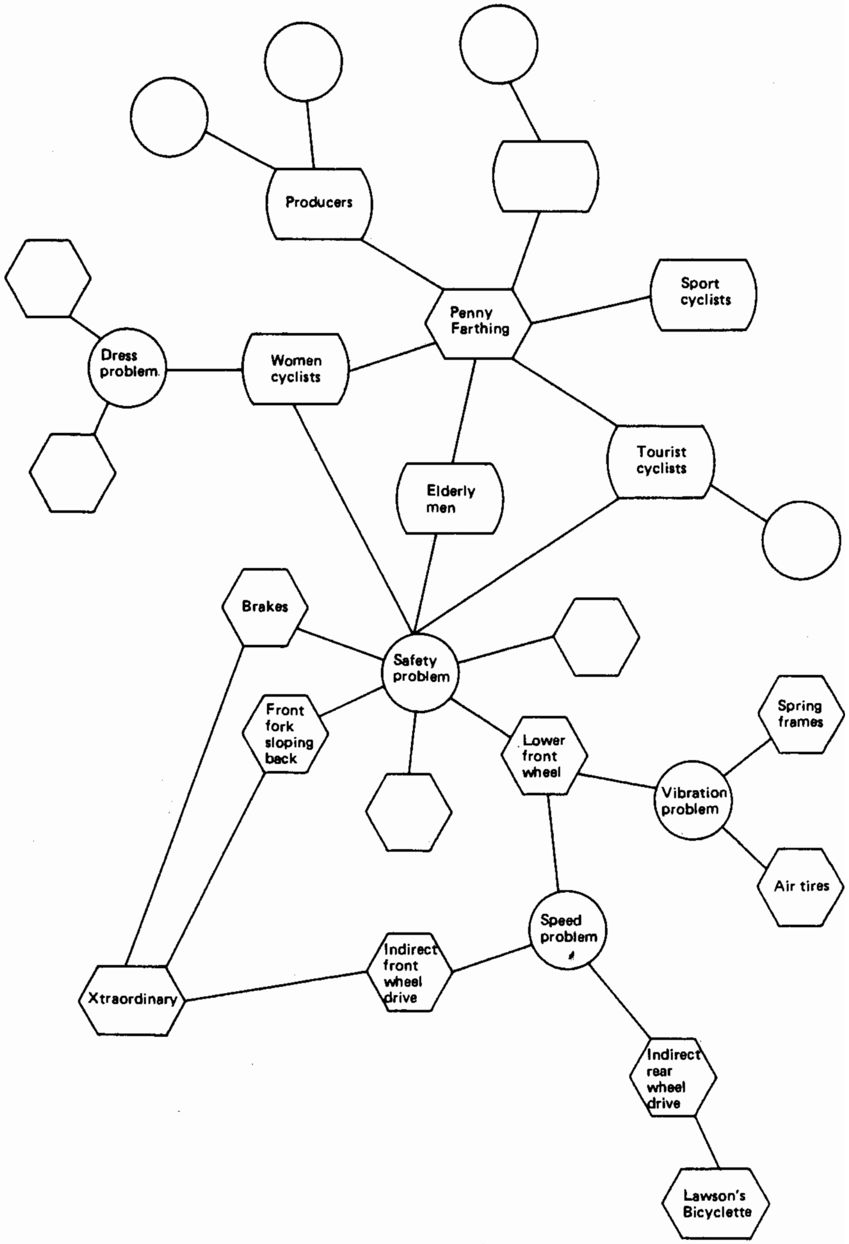

Figure 2.13
Three levels of evolutionary processes may be compiled by superposing figures such as 2.10, 2.11, and 2.12, onto figure 1.4

2.6 Solutions to the Safety Problem of the Ordinary

A great variety of solutions were tried to tackle the safety problem, once it was recognized by manufacturers and inventors. I will discuss them under three rubrics: three-wheeled cycles, modifications of the basic scheme of the Ordinary, and some more radical departures from that basic scheme.

Tricycles

It would be only partly true to describe the tricycle as a solution to the safety problem of the Ordinary, because parallel to the development I have described, from the Draisienne to the bicycle, another genealogy could be drawn of human-driven vehicles with three and four wheels, starting for example with the inventions of Demetrios of Phaleron (308 B.C.) and including the machines of Drais von Sauerbronn (1814).[39] None of these machines, however, reached a stage of commercial viability, and it is unlikely that these designs ever led to more than one prototype. Given the quality of the roads, it is not surprising that these vehicles could not compete with horse-pulled carriages. Moreover, those who could afford such a machine normally would prefer not to propel the "muscle-power cart" themselves—although some of these machines were big enough for servants to ride along and propel, leaving ample space for the owner to enjoy the ride at ease.[40]

A few inventors tried to overcome the disadvantages of the hobby-horse by developing heavy machines with three and four wheels, but none of these went beyond the prototype or toy stage (Woodforde, 1970: 13–15). But in the early 1870s the situation changed. The bicycle had created a market for human-propelled transport vehicles and when the safety problem of the Ordinary had been identified, the tricycle was reinvented as a solution. Moreover, the tricycle promised to solve the problem of staying upright, which many new and less athletic riders found difficult. One of the first successful tricycles was designed by James Starley. The "Coventry Lever Tricycle," patented in 1876, was a two-track machine, originally driven by a lever gear. The lever mechanism was soon changed to a chain drive (Caunter, 1958: 8). This machine became quite popular, especially among lady cyclists. Other designs followed, using all possible schemes to combine the three wheels (see figure 2.14). Propelling the tricycle on the pair of parallel wheels, as for example on the "Coventry Front-Driving Tricycle," caused problems. Because the two wheels were fixed on the axle, the smallest turn caused tension in the axle, then friction between the two wheels and road, thus making the tricycle swerve. This would happen when meeting a stone, let alone when the machine turned a corner, and the parallel wheels followed circles with different radiuses. The first solution was to let one of the parallel wheels run loose or with a friction coupling on the axle. James Starley developed a solution that is still used in all modern motor vehicles. He is reported to have made such a swerving maneuver one day, when he was cycling with his son William. They were riding a strange contraption called the "Honeymoon Sociable," consisting of two high-wheeled Ordinaries with axels fixed rigidly together to form a four-wheeled two-seater. After their unhappy landing, when sitting in the bed of sticking nettles at the roadside and applying a dock leaf to his hands, Starley got the idea of the differential gear: don't connect the two axles

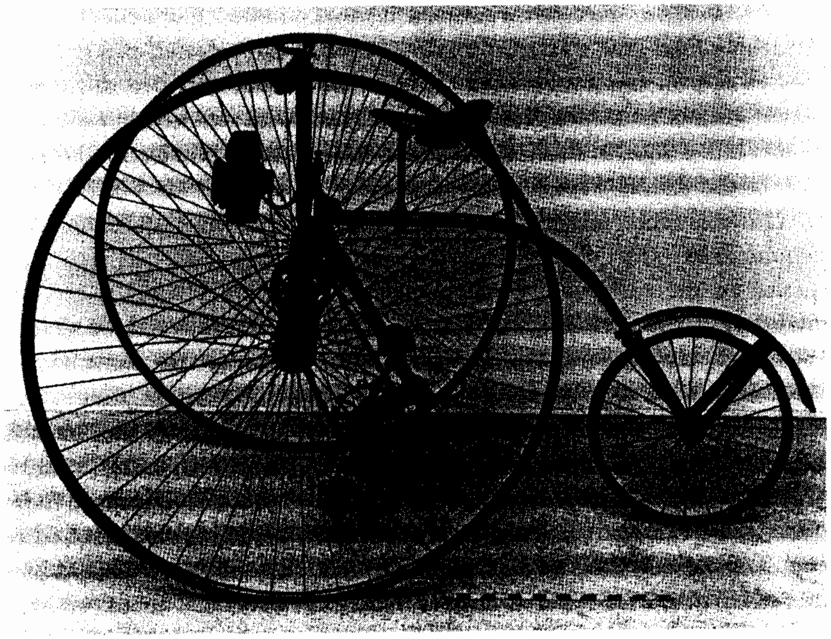

Figure 2.14
The Doubleday and Humber Tricycle was a great success on the racing track, but because of its tendency to swerve on passing over a stone it was not much used as a roadster. The front wheels, also used for steering, are driven by a chain; the right wheel is mounted solidly on the axle, while the left wheel has a nonrigid connection to the axle to allow for different rotation speeds when turning a corner. Photograph courtesy of the Trustees of the Science Museum, London.

rigidly, but use two bevel wheels in the middle. Immediately after returning home, he started to make a model of this device and the next day he left for the patent office in London.[41] Starley applied this differential gear to a new tricycle, the Salvo Quad, with one steering wheel in front and a fourth small trailing wheel for extra stability in the rear (hence the "quad").

Tricycles were advertised as being adapted to the requirements of women and elderly men. Their novelty gave them—just as had happened to the early velocipedes—a social cachet too. And indeed the aristocracy did go for it, especially after the invention received Queen Victoria's blessing. Williamson (1966) described how this came about. During one of her regular tours on the Isle of Wight in June 1881, Queen Victoria had seen what seemed to be a young woman amid a flashing mass of spinning spokes. Her horse carriage was unable to catch up with this amazing sight, and the Queen could not inspect more closely. Servants were sent out to track down the young woman and to summon her to the royal residency at Osborne House. The girl was found to be Miss Roach, daughter of the local Starley agent who encouraged his daughter, for promotional reasons, to ride the new Salvo Quad as much as possible. She came to Osborne House and demonstrated the tricycle to the Queen, who "must have been gratified to see that her performance was really very graceful and one which by no stretch of the imagination could be termed 'unladylike'" (Williamson, 1966: 76). Queen Victoria was interested enough to order two tricycles immediately, and a royal command was added that the inventor should be present on delivery. Thus, a few weeks later, James Starley, very nervous and with a brand new silk hat, traveled to Osborne House where the Salvo Quads were delivered through the local agent. The Queen was sitting on the lawn on a small garden chair, reading papers with a secretary; Prince Leopold, then about twenty-seven years old, was examining one Salvo Quad the stood under a tree. Starley was presented to the Queen, who said some pleasant words to him and gave him a leather case containing a silver watch as a memento of his visit. Then, Starley wrote in a letter to his wife,

> I was quite overcome and bowed so low that I nearly toppled over as I said I am very honoured, Ma'am. Then the gentleman led me away and I was surprised and pleased when the Prince came along and asked me to explain the working of the tricycle to him. A servant was wheeling it behind. We found a nice level drive where I got on and was soon rolling along in fine style. He seemed very pleased with it and thanked me very kindly.[42]

The Salvo Quad was immediately renamed into Royal Salvo, and within a few years the tricycle had become fashionable among the elite. Lord Albemarle wrote that there was not a crowned head who had not a fleet of tricycles, both within and outside Europe:

> I have seen a picture in which the Maharajah of an Indian state, together with the British resident at his court and all the great officers of the durbah, are seated on tricycles at the gate of the palace, and gaze at the lens of the camera with the breathless attention usual on such occasions.[43]

It was no surprise then that the Tricyclists' Association sought special privileges in the London parks because tricyclists were supposed to be better bred than bicyclists.[44] And in 1882 a Tricycle Union was founded, because many tricyclists wanted to distance themselves from the bicyclists, "who are a disgrace to the pastime, while Tricycling includes Princes, Princesses, Dukes, Earls, etc." (Ritchie, 1975: 113).

It is difficult to appreciate the importance of the tricycle in hindsight, as most of us associate the tricycle with children. However, the tricycle was a very viable alternative to the bicycle in the 1880s and 1890s and not some "historical mistake," as it may seem now. Most cycle manufacturers produced bicycles as well as tricycles.[45] For example, Messrs. Singer & Co manufactured a tricycle in 1888 that embodied the same state-of-the-art technology employed in their 1890 bicycles. A 1886 catalogue of all British cycles described 89 different bicycles and 106 tricycles.[46] Thus, notwithstanding the initial efforts to restrict the use of tricycles to the upper class, the tricycle gained widespread acceptance. In 1883, the "Bicycle Touring Club," founded in 1878, changed its name to the "Cyclists Touring Club." Many people were convinced that it would just be a matter of time before the tricycle was the only commercially available cycle (Rauck et al., 1979: 60). Especially as a vehicle for business purposes, it seemed to have a splendid future. The *Evening Standard* was distributed by means of the Singer tricycle called "Carrier," and the Post Office employed scarlet tricycles for delivering parcels. A specific illustration of the impact the tricycle had on designers of the time features the Otto Dicycle (see figure 2.15). This was a bicycle in the sense that it had but two wheels, but they were arranged in a "tricycle way": the dicycle had two large parallel wheels, and the rider was seated in between. The machine enjoyed some popularity; the Birmingham Small Arms Co. built 1,000 machines of this design. The "Ottoists" claimed that their dicycle was especially effective when riding against the wind,

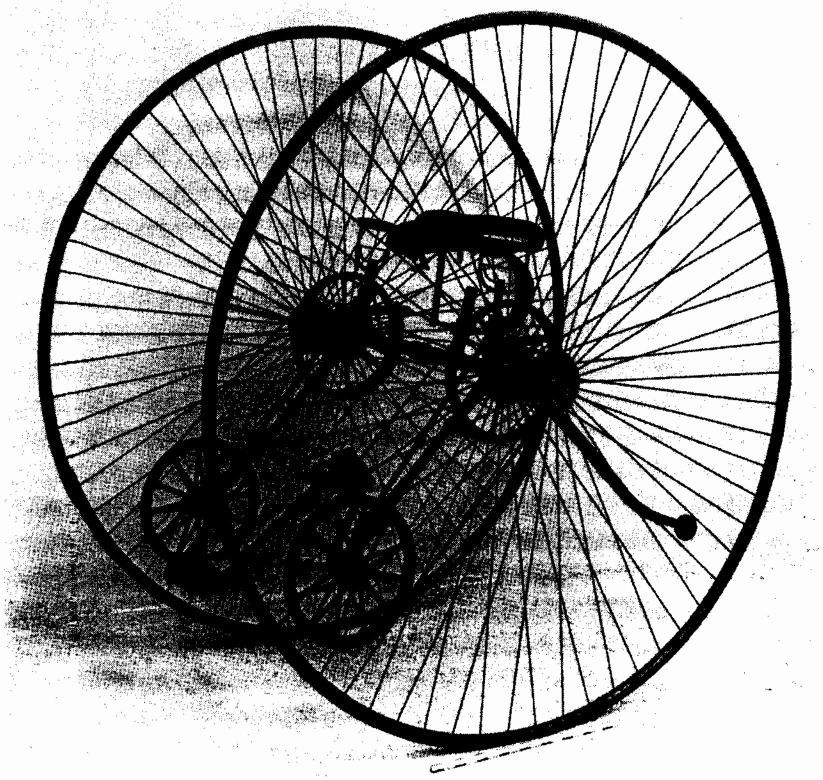

Figure 2.15
The Otto Dicycle was patented between 1879 and 1881 by E.C.F. Otto. From the back of the frame, supported by the axle, projects a small rubber-tired roller, which prevents the frame and rider from swinging too far backward. This roller can be used as emergency brake by leaning back; normally it will be well off the ground. The wheels turn loose on the axle and are driven by two rubber-sheathed pulleys. Handles on each side of the rider allowed the pulleys to be slackened selectively, so that one wheel could turn faster than the other and the machine could make a turn. Although keeping one's balance was said to be rather easy, steering downhill took longer to master. Photograph courtesy of the Trustees of the Science Museum, London.

because by leaning forward the riders could get out over the pedals, thus bringing all their weight to bear directly on them.

As mentioned, the tricycle played an important role in providing an opportunity for women to cycle. The acceptability of women riding tricycles was linked to the association of tricycling with the upper classes: "Tricyclists will generally be of a better class than bicyclists, and will seldom consist of mere beardless youths, but men of position and experience, and above all, by the fair sex."[47] Tricycling made it possible for young ladies of good breeding to get out of their stuffy Victorian homes. The tricycle (as some time later the bicycle) was not so much used by women to go somewhere, but rather to get away. And thus it showed the way to a loosening of customs, for example in the domain of dress. The Cyclists Touring Club seriously discussed the dress that should be worn by lady tricyclists (Woodforde, 1970: 123). The crucial element was assuring propriety by wearing knickerbockers or trousers beneath a full-length skirt. Still, this English "C.T.C. uniform" was a long way from the American "Bloomers," which will be discussed later. "One reason for the protection which ladies undoubtedly find in the C.T.C. uniform lies in the fact that it is so little remarkable, and so closely resembles that ordinarily worn by the wife of the parson or doctor."[48] Tricycling, too, was an activity during which a woman should not display herself too freely. But even so, tricycling engaged women in cycling and thus paved the way for women's participation in bicycling. Because the tricycle was appreciated for solving the safety problem of the high-wheeled Ordinary and thereby allowing women and elderly men to engage in cycling, it made bicycle producers acutely aware of these groups as potential markets for bicycle sales. This was further stimulated by recognizing that the tricycle was not without problems itself.

Surely it was more easy to keep one's balance on a tricycle than on a bicycle, and making a "header" was less likely too. But the tricycle appeared to have safety problems of its own. Most tricycles had three tracks, where the bicycle had only one when riding straight on. This made the tricycle more subject to the perils of the roads, for it was more difficult to avoid stones and holes. On the roads of the 1890s, this was a considerable drawback. Another circumstance that caused tricycles to be involved in accidents was that most of them did not have effective brakes. The rider had to "reverse the action of his machine" by trying to backpedal. And this could be difficult. Especially when going downhill, it was crucial not to let your feet slip off the pedals. When trying to regain control over those more and more quickly revolving pedals, many tricyclists were lifted from their seats. As a passing cyclist commented when helping a tricyclist after such a downhill accident, "You lost control. Should never do that, you know. Might have ruined your machine."[49]

Further, sitting between the two large wheels, as required by most tricycle configurations, was a safe and stable position as long as you were rolling along smoothly, but it became a very hazardous place to be when taking a spill. In such a case, it was almost impossible not to get entangled in the spokes of the large wheels. In 1883, tricycle accidents seem to have outnumbered accidents with bicycles, and the *Times* of that year reported a death caused by a fall from a tricycle (Woodforde, 1970: 67).

Thus the tricycle offered a partial solution to the safety problems of the Ordinary, and therefore it was a substantial commercial success. By the 1920s new tricycles were still used and sold, although few large cycle manufacturers were producing them. Instead, local assemblers were the typical producers of these custom-designed machines (Grew, 1921: 22). But since these machines posed some new problems of their own, the success was not complete and there was room for alternative solutions to the Ordinary's safety problem.

Safety Ordinaries

Another class of attempts to solve the high-wheeler's safety problem was based on modifying the basic scheme of the Ordinary bicycle. Moving the saddle backward was an obvious way to reduce the problem; without further modifications, however, this would bring the rider's weight above the small rear wheel and thus make its vibration more manifest. The only way to cope with this vibration problem was to enlarge the rear wheel. An additional advantage was that once the rear wheel was of significant size, the rider was positioned between the two wheels, rather than above one; this would also reduce vibration.[50] But this alteration made the bicycle heavier and thus more difficult to handle. Moreover, such an enlarged rear wheel was out of syne with the aesthetic norms of the community of high-wheel bicyclists, where the smallness of the rear wheel emphasized the loftiness of the rider. However, because the goal of making the Ordinary safer was already out of sync with the high-wheelers' norms, bicycle designers were probably prepared to put up with this drawback, expecting the relatively bigger rear wheel to be acceptable to potential buyers of these new machines. This new class of bicycles was soon to be called safety Ordinaries.

Another disadvantage of moving the saddle backward was that treading the pedals became less comfortable: because he was now behind the pedals rather than almost directly above them, the bicyclist, as in the case of the velocipede, would push himself backward with his legs, and counteract that force by pulling forward on the handlebar. One way to tackle this problem was to replace the pedals with some lever mechanism extending backward. John Beale had already patented such a mechanism in 1869, but its application in a commercial bicycle had to wait until about 1874, when the Facile bicycle was produced by Ellis & Co in London. The front wheel was reduced in size to 44 inches, the saddle was placed farther back, and the pedals were lowered by placing them on the rear ends of levers mounted below the axle. These levers were pivoted to forward extensions of the fork and their midpoints were connected to the cranks with short links (Caunter, 1958: 8).

On the Facile, the rider's feet made an up-and-down movement, rather than a rotary action. This was claimed to be very effective, especially when climbing a hill (see figure 2.16). The question of which of the two types of motion was best for cycling was hotly debated at the time. As was so often the case in bicycle history, enthusiasts tried to settle this issue by testing the bicycles in races and record-breaking efforts. Significantly, the Facile was not used for high-speed racing and sprinting, but primarily for hill climbing and long-distance riding (Griffin, 1886: 32). The rotary motion was generally preferred for sprinting (Ritchie, 1975: 126).

In 1878, G. Singer patented a device similar to the Facile (Singer, 1878). In this design, named the Xtraordinary, the backward position of the saddle was realized by tilting the front fork backward (see figure 2.17). However, such a sloping front fork, without further modification, would have made steering quite difficult: the center of the wheel—and thus the point of action of the bicycle's weight—was forward of the point at which the wheel had contact with the ground, and so the wheel tended to veer sharply and needed to be kept straight by continuous application of force. This problem was solved by the idea (also included in this patent) of giving the front fork such a form that the center line of the steering head met the ground at the point of contact between wheel and ground. The pedals of the Xtraordinary were brought backward by mounting them on levers that moved the crank pins. The upper end of each lever, attached by a link to a point near the top of the front fork, moved in an elliptical arc while the pedals made their "normal" rotary movement (Caunter, 1958: 9).

Although in the case of the Xtraordinary, the rotational speed of pedal and crank was still the same, one could choose different force-movement

June 4th, 1884. THE CYCLIST. 585

THE "FACILE"

SAFETY BICYCLE.

LAND'S END TO JOHN-O'-GROAT'S

ALL PREVIOUS RECORDS BEATEN.

1880. Blackwell & Harman 18 days.
1881. Jas. Lennox 12 ,,
1882. Keith-Falconer 13 ,,
1882. A. Nixon (Tricycle) 14 ,,
1883. Jas. Lennox 10 ,,
1884. J. H. ADAMS, 48in. 'Facile.'
6 DAYS 23 Hours 45 Minutes.
1884. H. R. GOODWIN, 38in. 'Facile.'
8 DAYS 45 Hours.

Total distance, [illegible] Miles. Average per day: Adams, [illegible] Miles; Goodwin, [illegible] Miles.

[illegible]

ELLIS & CO., Ltd.

165, [illegible]

Figure 2.16
The "Facile" was advertised by referring to the records set in long-distance racing. The riders performing these feats were often paid by the manufacturing firm: the first "professional" bicyclists. (From an advertisement in *The Cyclist*, June 4, 1884: 585; reprinted from Ritchie (1975).)

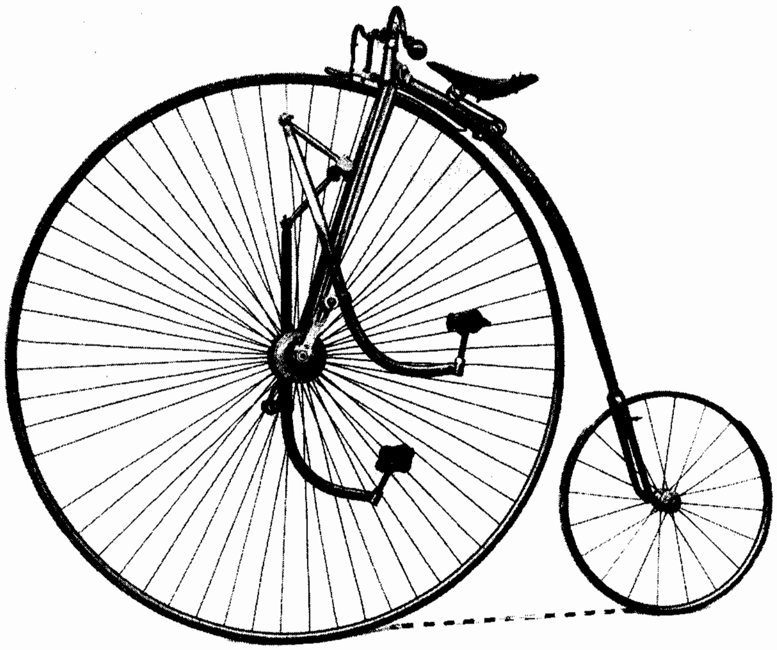

Figure 2.17
The "Xtraordinary," or "Xtra" for short, was produced by Messrs. Singer & Co., Coventry, in 1878. The levers allow the rider a downward push, although the saddle is moved backward. Photograph courtesy of the Trustees of the Science Museum, London.

ratios by varying the length of the levers and the position of the linking point of the crank pins. In principal this was no different from choosing specific lengths of cranks as possible in earlier models, but here the lever mechanism was mode more flexible (Griffin, 1886: 11). The levers of the Facile and the Xtraordinary perhaps point to the designers' growing awareness of the gearing possibilities of using "intermediate" driving mechanisms. In any case, several designs were tried to solve the Ordinary's safety problem, primarily by lowering the front wheel, and as an intrinsic part of that modification, to incorporate an accelerating mechanism to compensate for the resulting lower top speed.

Complicated combinations of levers and gears were employed in the Sun and Planet, the Devon Safety, the Dutton Safety, and the Raccoon Safety.[51] These machines still had the upright front fork and the forward-positioned saddle of the Ordinary, but their front wheels were significantly lower. None of these became a commercial success.

In Marseille, Rousseau was the first to add a chain drive to an Ordinary. He designed a bicycle called Sûr in 1877 that had a front wheel with a radius two-thirds that of an Ordinary. The wheel was driven by a gears-and-chain mechanism with a gear ratio of 2:3, exactly compensating for the smaller wheel radius. The Sûr, however, was not successful either, although a very similar design by E. C. F. Otto and J. Wallis did become a commercial success in Britain. Their Kangaroo had a front wheel of 36 inches, which was geared up to 54 inches (see figure 2.18). One problem with their mechanism was the arrangement with two independent chains: each pedal had to be raised by the "slack" side of its chain, which caused, unless it was kept carefully tightened, two shocks per revolution, jarring the gear (Caunter, 1958: 9–10). The Kangaroo

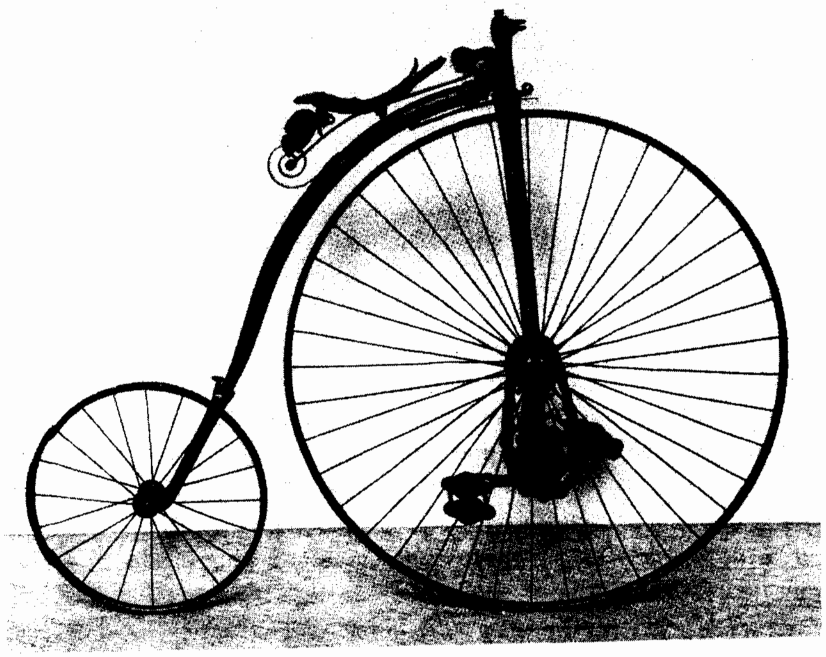

Figure 2.18
The "Kangeroo" safety Ordinary, patented in 1878 by E.C.F. Otto and J. Wallis, was built by several well-known manufacturers. Photograph courtesy of the Trustees of the Science Museum, London.

was manufactured by the firm of Hillman, Herbert, and Cooper. They publicly launched the Kangaroo in 1885 by organizing a race, which the professional cyclist G. Smith won on a Kangaroo. The average speed he obtained (14 miles per hour; 22.4 kilometers per hour) was more than twice the speed Hillman and Starley had achieved in their historic ride from London to Coventry. The Kangaroo scheme was taken up by several designers, and in the 1886 catalogue of bicycles some ten different makes of chain-driven Ordinaries were described (Griffin, 1886).

These safeties were claimed to be safer than the Ordinaries: the Facile, for example, was hailed by its makers as "Easy to learn. Easy to ride. Easy to mount. Easy to dismount. Safe from side-falls. Safe from headers."[52] And not only the manufacturers were enthusiastic. New bicycles were routinely tested and reviewed in the various journals, and most of these new machines were well received. For example, the Kangaroo was said to be

> a thoroughly sound and reliable little mount, likely to win its way more and more into popular favour, particularly among those who value their necks too highly to risk them upon the ordinary bicycle, or who are occasionally apt to characterize the propulsion of a heavy three-wheeler—as Dickens' friend did the turning of the mangle—as "a demm'd horrid grind."[53]

But from the advice given by *Cycling* in 1887 about coasting on a Kangaroo, the conclusion can be drawn that there was still considerable chance of being sent flying over the handlebar. A Kangaroo rider was cautioned to "throw his body as far back as possible" and to apply the brake very gradually. Thus the greater safety of the safety Ordinaries seems to boil down to falling less hard rather than less often.

One rather colorful solution left the height of the Ordinary unmodified, and only sought to enable its rider to land on his feet in case of a header. Franz Schröder constructed a safety handlebar, or "Non-Header" or "Non-Cropper" as he proposed to call it. When colliding head-on with some obstacle, the rider would be projected forward along with the handlebar, which disconnected automatically from the front fork (Rauck et al., 1979: 51). Schröder arranged a demonstration for the director and chief engineer of the bicycle manufacturing firm Frankenburger & Ottenstein in Neurenberg. When Schröder ran into the large stone that he had brought to the demonstration, he landed squarely in front of the Ordinary, on his feet. The director was wildly enthusiastic but the engineer less so, wondering what would happen to a somewhat less athletic rider. They summoned a worker to test the device, and he indeed landed on his bottom. This was nonetheless considered an improvement over landing on his head, and the "Non-Header" entered into production. The invention, however, did not fundamentally change the course of events by solving the Ordinary's safety problem in the eyes of all. A bitter patent fight evolved between Schröder and a Czech named Havlik who had simultaneously patented a similar device. In addition to challenging the fact that Schröder's invention had predated his own, Havlik also disputed its effectiveness, claiming that it would castrate its rider because a part of the steering tube was left on top of the front fork. Moreover, consumers were sending angry letters to Frankenburger & Ottenstein, complaining that the handlebar disconnected after only a minor push during regular cycling; frantically trying to keep control of the bicycle by holding on to the front fork, hapless riders inevitably landed on the ground entangled in their Ordinary (Timm, 1984: 194–202).

Reordering the Basic Scheme

All bicycles inspired by the safety problem of the high-wheeler were developed in roughly the same period and to some extent in parallel. Ordinaries, tricycles, safety Ordinaries, and the machines to be discussed in this section were all striving for the cyclists' favor. Considering the uneven quality of the historical material and the inevitable overlap of the various designs, it is hazardous to lend much weight to the chronological order as distilled from available sources. For example, the bicycles described in this section cannot be considered to form a logical follow-up to the safety Ordinaries of the previous section. Moreover, they do not bear much relation to one another. These designs deserve a separate discussion, because they differed more radically from the basic scheme of the Ordinary than the machines previously described.

One radical solution to the Ordinary's safety problem was to reverse the order of the big and small wheels. One bicycle that can be viewed as the outgrowth of this idea was patented by Henry J. Lawson and J. Likeman in 1878. Others, discussed below, were primarily of American origin. The Lawson and Likeman bicycle bore a close resemblance to MacMillan's machine. But when its frame is closely analyzed, the Lawson and Likeman bicycle clearly reveals its origin as an Ordinary. However, it is driven backward. To bring the rider within reach of the handlebar, which was of the normal Ordinary construction but now mounted on the small wheel, the saddle had to be moved to a position between the wheels. This low positioning of the saddle enabled the cyclist to reach the ground with his feet while staying on the bicycle (Caunter, 1958: 8). Indeed, this machine could have been called a "safety."[54] However, it seems not to have been much of a commercial success.

Another family of bicycles, designed according to the same basic idea, did meet with success. Viewed from a distance, the obvious difference with the previous design was the position of the rider, who sat much more on top of the large wheel, which had consequences for the steering mechanism. Several patents were taken out on designs according to this scheme.[55] The available sources are ambiguous about the construction date of the first successful bicycle of this principle. One of the first of these machines was probably produced by the H. B. Smith Machine Company of Smithville, New Jersey, and publicly exhibited at the meeting of the League of American Wheelmen in Boston, on November 23, 1981.[56]

The Star bicycle, as the Smith machine was called, had its saddle forward of the big rear wheel and thus needed a lever-type of driving mechanism to bring the pedals forward to the position of the rider's feet (see figure 2.19). Two drums were attached to the ends of the rear axle.

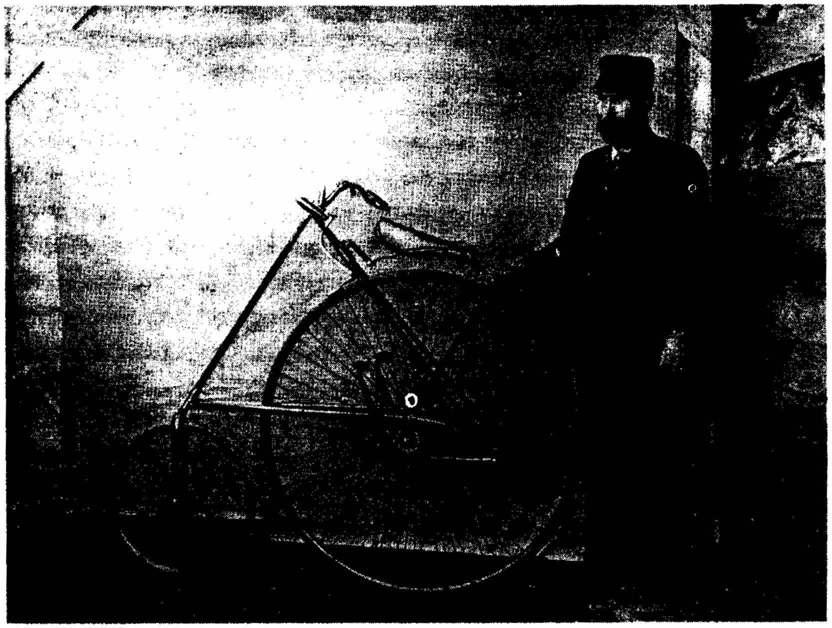

Figure 2.19
The American "Star" bicycle, first manufactured around 1881. Photograph courtesy of the Trustees of the Science Museum, London.

A leather strap was wound around each drum several times, one end of the strap being attached to the drum and the other end to the lever on that side. As a lever was pushed down, its strap was pulled, which made the drum turn. The drum was attached to the axle by a ratchet mechanism and thus forced the wheel to turn as well. At the end of a stroke, the foot pressure was released and a spring within the drum wound the strap back, bringing the lever to its original position. The effective attachment point of the straps on the levers could be adjusted, thus providing a kind of "gear shift," as two different driving ratios were possible.[57] Normally the levers would be pushed down alternatingly, but because they worked independently of each other, they could be pressed down together in one big stroke. This was considered an advantage for racing purposes, to obtain a quick start or produce a spurt (Caunter, 1958: 14).

Although the small front wheel of the Star suggests difficulty in steering as well as in coping with rough ground, this seems to have been compensated for by its safety and the advantages of the driving mechanism.[58] The Star had considerable success in the United States. But although it was sold in Europe, it did not acquire a significant share of the market in Britain or on the continent.[59] Perhaps the Star was evaluated in comparison with the safety Ordinaries and not found a very credible competitor. In turn, the British safety Ordinaries did not obtain a foothold in the United States.

Another way of reordering the basic scheme of the Ordinary was to move the drive to the rear wheel. In 1879, H. J. Lawson, by that point manager of the Tangent and Coventry Tricycle Company, took out a patent on a design of a bicycle that had a chain drive on the rear wheel (see figure 2.20).[60] The diameters of the wheels revealed its origin: the Ordinary. Now the only function of the relatively large front wheel was to offer a comfortable ride, but the comfort was reduced by the still quite small rear wheel. Because the saddle was mounted on a spring, the result may have been acceptable, though. The front wheel was 40 inches and the rear wheel 24 inches, but geared up to 40 inches as well (Caunter, 1958: 10–11). Lawson called his machine a "Bicyclette."

Whereas the latest types of Ordinary were considered slim and graceful, the aesthetic aspect of the Bicyclette was not much appreciated. Both the public and the trade just could not swallow the grotesque form of the Bicyclette, which was compared to a crocodile because of its elongated frame.[61] A small number of Bicyclettes were manufactured, but they proved to be a commercial failure even though they were rather extensively advertised and exhibited. In many bicycle histories the Bicyclette is said to be "ahead of its time."

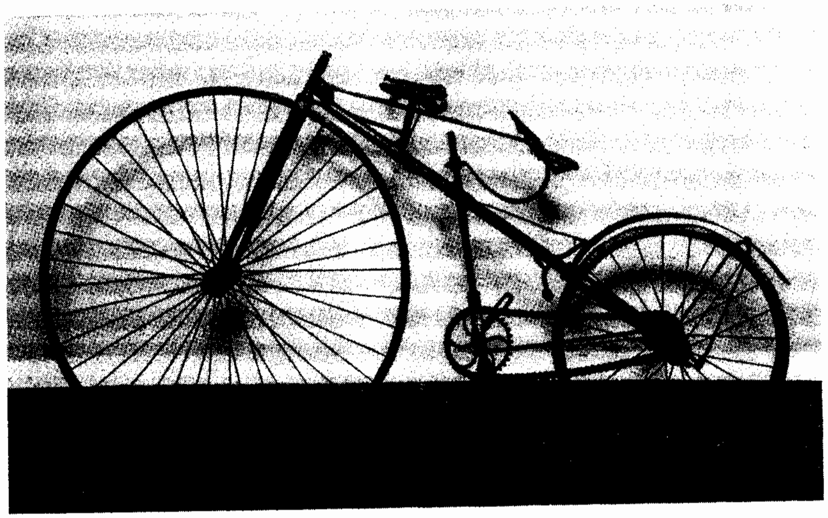

Figure 2.20
Lawson's "Bicyclette," patented in 1879. Photograph courtesy of the Trustees of the Science Museum, London.

Although Lawson's Bicyclette was not successful, in the early 1880s there was enough awareness of the safety problem of the Ordinary to stimulate further attempts along these lines. A real boom of different bicycle designs occurred between 1884 and 1888: besides new Ordinaries, safety Ordinaries, and tricycles, lower-wheeled bicycles proliferated. Frequently the words "dwarf" and "safety" were combined in their names. John Kemp Starley, a nephew of James Starley, had started a partnership with William Sutton. After manufacturing Ordinaries and tricycles for some years, they presented in 1884 a new design, comprising a 36 inches front wheel, coupling-rod steering, a chain drive to the rear wheel, and a frame that seemed, when viewed from a distance, to have a diamond shape (see figure 2.21). This machine, named the Rover, is a curious mixture of elements found in the other bicycles described in this section. The relative size of the wheels, the chain drive, and the steering mechanism are very similar to Lawson's Bicyclette, while the main tube of the frame is formed like that of the Star (and the Ordinary). New is the extra support of the saddle by a fork on the rear wheel. This extra support would soon develop into a true part of the

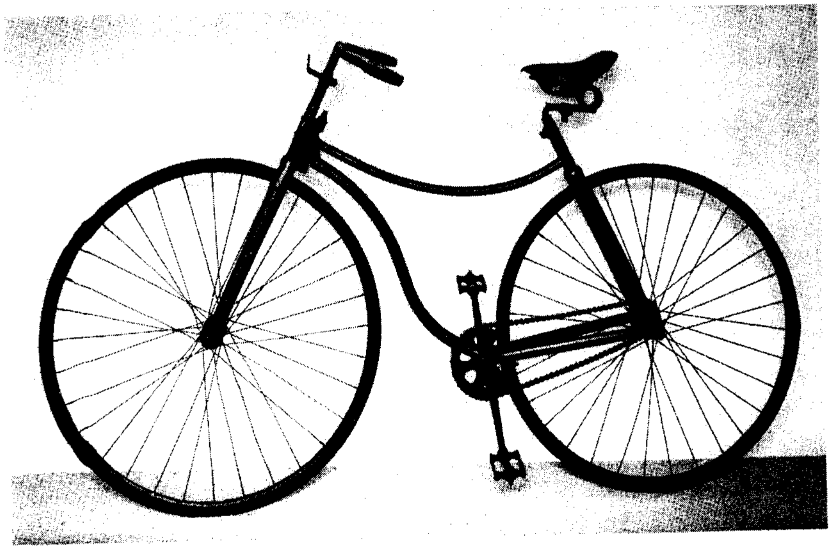

Figure 2.21
"The Rover," designed by J. K. Starley and W. Sutton in 1884, was the first dwarf safety with a diamondlike frame. Photograph courtesy of the Trustees of the Science Museum, London.

frame, thus resulting in the diamond-shaped frame that most (male) bicycles would have up to today. Effectively, however, the Rover still had a single backbone frame.

The Rover was presented to the public during the Stanley Exhibition, a large annual event held in London. All important cycle manufacturers sent their latest models for display, and all members of the trade came to keep abreast of recent developments and to place orders for the coming year. Starley and Sutton's new Rover must have seemed a pygmy among all the lofty Ordinaries. Some traders approved its small wheels and assumed it to be suited for nervous or less athletic cyclists. Others were inclined to scoff and nicknamed it "Beetle" or "Crawler" (Williamson, 1966: 103). Starley and Sutton started to organize races in which they had professional racers riding their Rover. For the first race Starley and Sutton used the same route Hillman had used for the launching race of the Kangaroo in 1885. They could be satisfied by this promotional move: the record set on a Kangaroo was beaten by the same George Smith, but this time on a Rover.[62] As the sales started to increase, Starley continued to revise his Rover, turning out a second and third model with only a few months in between. I will return to these revisions shortly.

Figure 2.22
From 1884 to 1886 several new designs were developed, in various aspects widely different from the basic scheme of the Ordinary bicycle. The Humber "Dwarf Safety Roadster," also designed in 1884, had a trapezial frame. In their model of 1886, Humber introduced a front fork with the forward bending of the Singer 1878 bicycle. Photograph courtesy of the Trustees of the Science Museum, London.

The new designs from the mid-1880s clearly show that all elements of the basic scheme of the Ordinary had been called into question (see figure 2.22). The Birmingham Small Arms Company, for example, made a bicycle of which the cross frame was radically different from all previous frames based on the single backbone of the Ordinary. This bicycle had a large chain-driven rear wheel and a small indirectly steered front wheel. The new frame consisted of an almost straight tube between the axle of the traveling wheel and the bracket for the steering front fork, and a second rod, perpendicular to the first, which supported the saddle, the indirect steering mechanism with handlebar, and the crank bracket with sprocket wheel. This invention had for its object "to give greater rigidity to the framing of the bicycle so that the seat and steering mechanism may be free from the unsteadiness of those parts in bicycles of the ordinary kind."[63]

Lawson played an indirect role in stimulating the design of this bicycle. He had approached B.S.A. with a proposal to manufacture his new design for a lady's safety bicycle. This machine had a large chain-driven rear wheel, a smaller front wheel, and a single-tube frame that bent upward and forward to support the saddle (Lawson, 1884). B.S.A. declined the offer but agreed to make two prototypes for Lawson. While doing that, they decided to design their own safety bicycle and assembled this machine as much as possible from their standard tricycle parts (Caunter, 1955: 35).

Another design that departed from the old frame scheme was patented by the gun maker H. Wallis in 1884 and produced by Messrs. Humber & Co (Wallis, 1884). Its frame had a trapezial form, which proved stiffer and more compact than the single backbone frame of the Ordinary bicycle. Another important feature, in comparison with competing 1884 designs, was its direct steering. The small front wheel proved to be problematic on rough roads, however.

J. McCammon patented a dwarf bicycle suitable for ladies. The single backbone of the frame dropped deep between the wheels, so as to allow women to mount the machine more easily (Caunter, 1958: 14). This McCammon bicycle had the same steering wheel scheme as the Humber, but also featured the slightly backward bending of the front fork that was used in the B.S.A. machine.

Starley and Sutton further revised their Rover by making the steering direct, giving the front fork much rake and changing the frame from the original single backbone to the beginning of a diamondlike shape. The front fork is straight, so it is not surprising that "at first the steering feels rather difficult, as the pilot wheel has no automatic assistance or fly-back spring to keep it straight" (Griffin, 1886: 44). It is unclear why they did not use Singer's idea, described previously, of bending the front fork to counter this effect. Nevertheless, consumer tester Griffin concluded his report on this Rover on a positive note, predicting a successful future for it.

In spite of the emergence of quite a number of dwarf safeties, many people still were convinced that the high-wheeled Ordinary bicycle would never be superseded by those geared-up small-wheelers. In a report on the yearly Stanley Exhibition of Cycles, it was observed that

> No radical changes have been made in the construction of cycles during the past year, and the tendency is to settle down to three types of machines—the ordinary bicycle, the rear-driven safety bicycle, and the direct front-steering tricycle, whether single or tandem. (Engineer, 1888a: 118)

Besides mud splashing on the rider's feet[64] and the power wasted by the chain drive, the most prominent problem was the vibration of the low-wheeler (Woodforde, 1970: 87).

At the 1888 exhibition most safeties were equipped with some sort of antivibration gear. Many frames were constructed with several hinges instead of rigid connections. Springs were mounted between the wheel axles and the frame, between handlebar and front fork, between saddle and frame, and between crank bracket and frame (Engineer, 1888a: 118). The awareness of the vibration problem seems to have increased in subsequent years. In the 1889 cycle show it was clear that

> With the introduction of the rear-driving safety bicycle has arisen a demand for antivibration devices, as the small wheels of these machines are conducive to considerable vibration, even on the best of roads. Nearly every exhibitor of this type of machine has some appliance to suppress vibration. (Engineer, 1889: 158)

In the report on the 1890 show, the situation is even more pronounced (Engineer, 1890b: 138). One of the spring frames that was most successful at the 1890 cycle show had been patented in 1885 by O. Macarthy. The machine was manufactured by Messrs. C. A. Linley and J. Biggs (see figure 2.23). The sloping backbone that joined the rear axle with the steering head and front fork was connected to the rest of the bicycle by springs and hinges. Thus all bicycle parts with which the rider had contact (the saddle, the handlebar, the cranks) had an elastic connection to the rest of the machine (Caunter, 1958: 14–15 and Caunter, 1955: 35–36). However, not many of the antivibration devices were strong and durable: "Of those exhibited for the first time too many are conspicuous by their complication; we should imagine that their designers were in many cases ignorant of the first principles of mechanics" (Engineer, 1889: 158). And of course, even the successful "Whippet" with its many movable parts needed more attention than an ordinary bicycle.

It is not surprising then that the safety bicycle was not more than one of the three alternative types of cycle, without threatening the market share of the other two, the Ordinary bicycle and the tricycle. This changed when the air tire was made available for bicycles.

2.7 *Interpretative Flexibility*

The bicycle story will be interrupted again to discuss another issue related to the descriptive model I am developing. In the previous sections I have described the various artifacts through the eyes of relevant

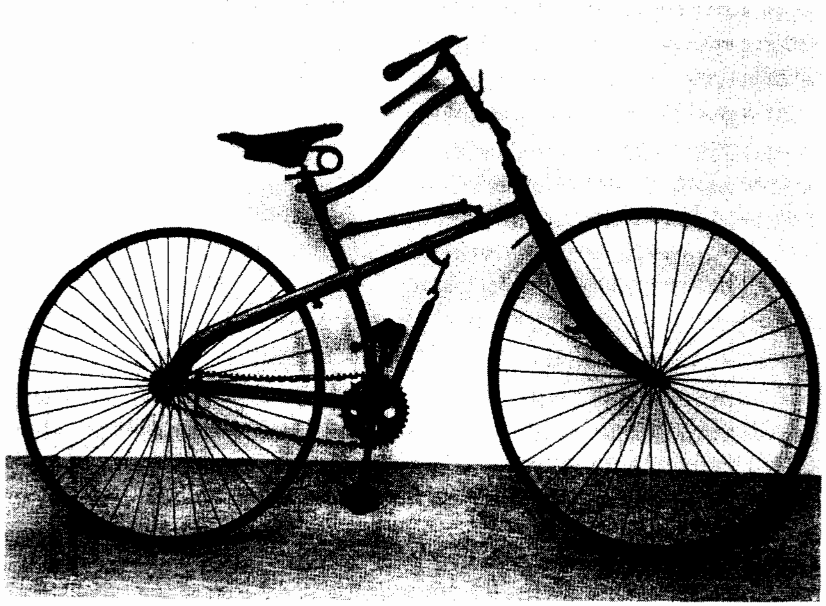

Figure 2.23
The "Whippet" safety bicycle was patented and built in 1885. The relative positions of saddle, handlebar, and cranks were fixed, since these three formed a rigid triangle that was isolated from the main backbone of the frame by a strong coil spring, a movable shackle in the steering rod, and a hinged tube between backbone and steering pillar. Photograph courtesy of the Trustees of the Science Museum, London.

social groups. Where the differences between the various social groups were taken seriously, quite different descriptions did result. Until this point, however, this was left rather implicit. I shall now discuss more explicitly the consequences of those differences in the meanings attributed to an artifact by various relevant social groups.

For example, for the social group of Ordinary nonusers an important aspect of the high-wheeled Ordinary was that it could easily topple over, resulting in a hard fall; the machine was difficult to mount, risky to ride, and not easy to dismount. It was, in short, an *Unsafe Bicycle.* For another relevant social group, the users of the Ordinary, the machine was also seen as risky, but rather than being considered a problem, this was one of its attractive features. Young and often upper-class men could display their athletic skills and daring by showing off in the London parks. To impress the riders' lady friends, the risky nature of the Ordinary was essential. Thus the meanings attributed to the machine by the group of Ordinary users made it a *Macho Bicycle.* This Macho Bicycle was, I will argue, radically different from the Unsafe Bicycle—it was designed to meet different criteria; it was sold, bought, and used for different purposes; it was evaluated to different standards, it was considered a machine that worked whereas the Unsafe Bicycle was a *nonworking machine.*[65]

Deconstructing the Ordinary bicycle into two different artifacts allows us to explain its "working" or "nonworking." There is no universal time- and culture-independent criterion with which to judge whether the high-wheeled bicycle was working or not. Is the Ordinary a nonworking machine because it was highly dangerous and very difficult to master? Or was it a well-working device because it displayed so nicely the athletic skills of the young upper class and because it dealt so effectively with bumps and mud puddles in the road? Only by reversing the question—that is, by asking under what conditions the high-wheeled Ordinary constituted a well-working machine and under what other conditions it was utterly nonworking—can we hope to begin to understand technical development.

In terms of the descriptive model, this implies the following. The artifact Ordinary is deconstructed into two different artifacts. Each of these artifacts, the "Unsafe," and the "Macho" are described as constituted by a relevant social group, and this description also includes a specification of what counts as "working" for that machine, for that group. In this way, the "working" and "nonworking" are now being treated as *explanandum,* rather than used as *explanans* for the development of technical artifacts. The "working" and "nonworking" of an artifact are socially constructed assessments, rather than intrinsic properties of the artifact. One artifact (in the old sense) comprises different socially constructed artifacts, some of which may be "working" while others are "nonworking." I am not primarily making a metaphysical claim here—I am stressing this point because in this way the descriptive model will allow for a symmetrical analysis of technology, as called for in chapter 1. This is analogous to arguing that "Nature" should not play a role as *explanans,* as David Bloor (1973, 1976) did in his strong programme.[66] "Nature" should not be invoked to explain the truth of scientific beliefs; and neither should specific sociological circumstances—such as the scientist being excessively ambitious, having a bad marriage, or living under a totalitarian regime—be used exclusively to explain the falsity of scientific beliefs. This "symmetry principle" calls for sociologists analyzing scientific development to be impartial with respect to the truth or falsity of scientific beliefs. They should explain truth and falsity symmetrically, that is, by using the same conceptual framework.

Thus I want to argue that the account of bicycle development can be adequately rephrased by distinguishing two separate artifacts: the Unsafe Bicycle and the Macho Bicycle. Although these two artifacts were hidden within one contraption of metal, wood, and rubber (the so-called Ordinary), they were not less real for that. This can be seen from the different designs spectrums they to which they belonged. The Unsafe Bicycle gave rise to a range of new designs that sought to solve the safety problem. Many of these efforts were described in the previous section: moving the saddle backward (Facile, Xtraordinary), adding auxiliaries (the "Non-Header"), reversing of the positioning of small and large wheels (Star), or making other radical changes to the basic scheme (Lawson's bicycle). The Macho Bicycle developed in the opposite direction: the front wheel was made as large as possible. This design trend produced important and lasting effects in bicycle technology, even though the high-wheeled Penny-farthing became obsolete in the end. The making of higher wheels, for example, necessitated the development of better (and specifically, stiffer) spoked wheels. To distinguish two different artifacts in this way is more straightforward than trying to cope with the wide spectrum of different designs, even though one needs some imagination to see them within that one Ordinary.

I will call this sociological deconstruction of the Ordinary into an Unsafe Bicycle and a Macho Bicycle "demonstrating the interpretative flexibility of the Ordinary." The possibility of demonstrating the interpretative flexibility of an artifact by deconstruction implies that there is an immediate entrance point for a sociological explanation of the development of technical artifacts. If no interpretative flexibility could be demonstrated, all properties of an artifact could be argued to be immanent after all. Then there would be no social dimension to *design*: only application and diffusion—or *context*, for short—would form the social dimensions of technical development. But demonstrating the interpretative flexibility of an artifact sets the agenda for a social analysis of the design of technology as formulated in the "working as result" requirement for a framework.

Indeed, demonstrating the interpretative flexibility of an artifact can only be the first stage in a social analysis of technical design. The sociological deconstruction of an artifact leaves the sociologist's desk full of pieces that have to be put together again. After all, the analyst may deconstruct the Ordinary into two artifacts, but that does not change the fact that late nineteenth-century English society eventually did construct the high-wheeled bicycle into *one* black box, eliminating the Macho Bicycle and focusing development efforts on the Unsafe Bicycle, thereby preparing the way for the Safety Bicycle. Thus the demonstration of the interpretative flexibility sets the agenda for a sociological analysis of technical development. Once an artifact has been deconstructed into different artifacts,[67] it is clear what has to be explained: how these different artifacts develop; whether, for example, one of them peters out while the other becomes dominant. In the bicycle case, the "Macho," although dominant in the beginning, was in the end superseded by the "Unsafe," and the Ordinary thus developed from a working into a nonworking machine. In the next sections I will follow this process in the case of the safety bicycle.

Relevant social groups do not simply see different aspects of one artifact. The meanings given by a relevant social group actually *constitute* the artifact. There are as many artifacts as there are relevant social groups; there is no artifact not constituted by a relevant social group. The implications of this radically social constructivist view of technology will be addressed in the remainder of this chapter, especially in the third intermezzo, section 2.9. Then I will discuss how the "pluralism of artifacts," brought to the fore by demonstrating the interpretative flexibility, will eventually be reduced again, when one of the artifacts stabilizes.

2.8 The Air Tire

In 1845 William Thomson, a civil engineer of Adelphi, Middlesex, had already found what we now view to be the solution of the vibration problem (see figure 2.24). He patented "elastic bearings round the tires of the wheels of carriages, for the purpose of lessening the power required to draw the carriages, rendering their motion easier, and diminishing the noise they make when in motion," (Thomson, 1845: 2). He did so by using "a hollow belt composed of some air and water tight material, such as caoutchouc or gutta percha, and inflating it with air, whereby the wheels will in every part of their revolution present a cushion of air to the ground or trail or track on which they run" (ibid.). One of the ways, specified by Thomson in his patent, to make this elastic belt was to cement together a number of folds of canvas with india rubber, then render the belt more pliable by immersing it in melted sulphur, and finally, provide a strong outer casing by sewing circular segments of leather around the tire. Pipes were provided, passing through the wheel

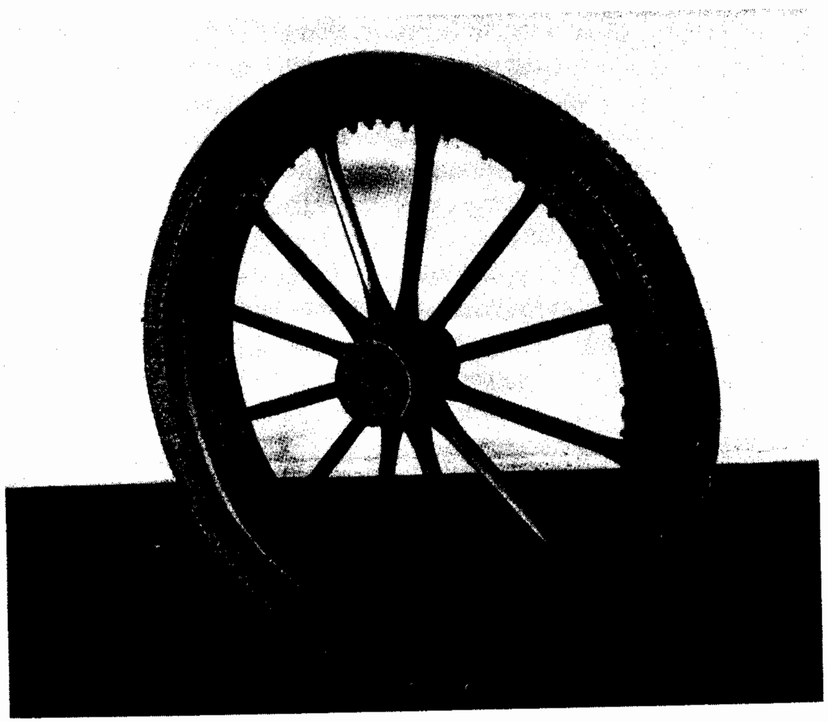

Figure 2.24
The first air-filled elastic belt was patented by R. W. Thomson in 1845. Photograph courtesy of the Trustees of the Science Museum, London.

and fitted with an airtight screw cap, to inflate the elastic belt. Thomson made wide claims in his patent and specified the application of his elastic belt to horse carriage wheels, to railway wheels running on timber rails, and to such objects as bath chairs and rocking chairs.

Thomson's belts were tried on horse carriages and found very useful. One journey of more than 1,200 miles is reported to have taken place without any damage to the belts.[68] A carriage-making firm, Whitehurst & Co. was licensed to produce the belts and started carrying out some promotional activities. In 1847 Thomson described some tests to compare the traction forces required by a carriage with elastic belts and one with iron wheels. Here he also presented an air pump very similar to the modern bicycle hand pump (Thomson, 1847). But soon this enterprise came to an end. Part of the explanation for this failure is probably that the belts must have been rather expensive. Moreover, in carriage construction other antivibration devices were feasible, such as large leaf springs and luxuriously cushioned seats. Apparently the small and light Safety bicycle was needed to create a market for this type of tire.

From the early 1870s onward, noninflated rubber tires represented the state of the art in bicycle construction. They came in various forms: solid rubber tires, cushion tires (containing air under atmospheric pressure), and rubber tires with some solid filling as reinforcement. By 1885 several adequate techniques for mounting the tire on the wheel were practiced and the kind of accident Hillman experienced during the famous ride with James Starley from London to Coventry rarely happened anymore. But the small wheels of the Safety bicycles caused too much vibration for these tires to handle. Thomson's patent, his article, and the constructions were completely forgotten in twenty years' time. When John Boyd Dunlop started to consider the idea of air-filled rubber tubes, he did the work all over again.

Dunlop, born in Scotland on 5 February 1840, was a veterinary surgeon in Belfast. He invented various special surgical instruments and was especially experienced in making rubber appliances (Caunter, 1958: 44; Du Cros, 1938: 33). What prompted Dunlop to start working on an air-filled bicycle tire is unclear. One story suggests that a doctor had advised him that cycling would be healthy for his son, but that it would be even more beneficial if the jarring could be reduced (Du Cros, 1938: 39). Another story depicts Dunlop as having long been interested in road transportation and purposefully searching for a means to reduce vibration. In the course of these efforts he constructed various spring wheels and flexible rims, and at last turned to rubber pipes.[69] There is agreement on the secret test ride that Dunlop's son Johnny made on the night of 28 February 1888, using his tricycle equipped with two new air tires on its rear wheels. After this test, which went well, Dunlop asked the bicycle manufacturing firm Edlin & Sinclair of Belfast to make him a new tricycle on which he mounted his air tires himself. When the tires passed this trial as well, he applied for a patent in June 1888.

In his patent Dunlop specified the use of his tires for "all cases where elasticity is requisite and immunity from vibration is desired to be secured," but he also mentioned the "increased speed in travelling owing to the resilient properties" of his tires (Dunlop, 1888: 1). Neither in later parts of this patent, nor in the next patents (Dunlop, 1889a,b) did he comment further on that second objective, and we will see that all early reports about the pneumatic tire focused on its value as an antivibration device. It is unsure how important the speed-increasing potential of his tires was for Dunlop, but judging by Thomson's experiments on traction forces, the latter seems to have been more aware of the friction-reducing possibilities than was Dunlop. This aspect of the air tire will play an important role.

Dunlop employed a hollow tube of india rubber, surrounded with cloth canvas or other material adapted to withstand the pressure of the air. This canvas or cloth was again covered with rubber or other suitable material to protect it from wear on the road (Dunlop, 1888: 1). The tire was provided with a nonreturn valve. In a separate patent he further developed this valve for specific application to bicycle tires (Dunlop, 1889a). Dunlop also mentioned in the patent "any ordinary forcing pump" to inflate the tire; according to his daughter, he had used Johnny's football pump for this purpose. In a third patent Dunlop specified a means for mounting the tires on the wheel rim (Dunlop, 1889b).

The first Dunlop tires were made by the Pneumatic Tyre and Booth's Cycle Agency in Dublin (Du Cros, 1938: 84). Two exhibition rides played an important role in the early days of promoting the air tires. The first was undertaken by R. J. Mecredy, the editor of an Irish cycling paper and a renowned cyclist, who rode from Dublin to Coventry on a tricycle fitted with the new tires. In Coventry he aroused great interest: "The tyres were quite unknown, and when the tricycle was left outside a hotel (not in the centre of the city) for ten minutes, a crowd of 400 or 500 people were found pushing each other to obtain a sight of it."[70] Within a few months everybody interested in bicycles knew all about the new tires. The second feat was a bicycle race held in Dublin. On 18 May 1889 all four races of the Queen's College Sporting Games were won by W. Hume on a "pneu bicycle." This proved to be important because the well-known Du Cros brothers appeared to be among the defeated cyclists. Their father, Harvey Du Cros, was impressed enough to buy Dunlop's patent rights and to found the Pneumatic Tyre Company in Belfast (Rauck et al., 1979: 108). This was the beginning of commercial production of the air tire.

The first tyres were very expensive: about £5 a pair, whereas a complete Ordinary or safety bicycle, fitted with solid rubber tires, cost only around £20. Apart from this, technical difficulties induced much skepticism within the trade, as is obvious from a report on the newly exhibited pneumatic tires at the Stanley Exhibition of Cycles in 1890:

> Not having had the opportunity of testing these tires, we are unable to speak of them from practical experience; but looking at them from a theoretical point of view, we opine that considerable difficulty will be experienced in keeping the tires thoroughly inflated. Air under pressure is a troublesome thing to deal with. (Engineer, 1890a: 107)

Besides this technical skepticism, the reporter also had arguments pertaining to road behavior and aesthetic complaints:

> From the reports of those who have used these tires, it seems that they are prone to slip on muddy roads. If this is so, we fear their use on rear-driving safeties—which are all more or less addicted to side-slipping—is out of the question, as any improvement in this line should be to prevent side slip and not to increase it. Apart from these defects, the appearance of the tires destroys the symmetry and graceful appearance of a cycle and this alone is, we think, sufficient to prevent their coming into general use. (Engineer, 1890a: 107)

Arthur du Cros's memories of his very first ride through London on an air-tired bicycle underline the same aesthetic disapproval:

> Omnibus and hansom drivers, making the most of a heaven-sent opportunity, had the time of their lives; messenger boys guffawed at the sausage tyre, factory ladies simply squirmed with merriment, while even sober citizens were sadly moved to mirth at the comicality which was obviously designed solely to lighten the gloom of their daily routine. (Du Cros, 1938: 54–55)

Another problem was that the tires were easily punctured. Repairing an original Dunlop tire was a job that the average bicyclist undertook only with fear and trepidation. Because the tires were cemented to the wheel, you had to peel back the solutioned tread of the rubber cover, then slit the canvas across and withdraw the air tube. Then you had to find the puncture, fix the patch, replace the tube, stitch up the canvas with needle and thread, refix the tread, and reinflate the tire. This task required more skill than many cyclists possessed, and wheels could be seen turning around with huge blobs on the tires where the amateur sewing and repairs were too weakly done to prevent the air tube from bulging out of the canvas and cover. The comfortable ride for which the air tires had been bought was rather spoiled by this. The blobs would hit the forks time after time while the wheel revolved, until the friction wore away the cover and bang went the tube again—but this time condemning the rider to the railways or a long walk (Grew, 1921: 54). Moreover, you needed to bring along a box of tools and materials to accomplish repairs.

However, like so often in the cycle history, it was on the racing track that the air tire's fate changed radically. Here it won its first and probably most important battle against the solid rubber tire. Hume's victory in Dublin in May 1889 had already led to the participation of Du Cros in Dunlop's enterprise. But further participation in races quickly spread the news. Spectators confronted with a "pneu bicycle" for the first time invariably hailed it with derisive laughter, but, as the racing cyclist Arthur du Cros (1938: 51) remembers, "to the stupefaction of the onlookers the ugly interloper outpaced all rivals so decisively that their derision was turned to hysterical applause." Within a year no serious racing man bothered to compete on anything else than air tires.

As to the specific way of mounting the tires, cycle makers had to send their wheels to the Pneumatic Tyre Company in Belfast where the tires were fitted. Obviously this presented a serious barrier to further increasing the sales of air tires. Du Cros decided to move his business to Coventry, the heart of the British cycle industry. Soon the Dunlop carts could be seen careering about Coventry, collecting the tire wheels and delivering them, fitted with air tires, back to the various factories (Grew, 1921: 54).

But then, in the autumn of 1890, Dunlop was officially informed that his patent was invalid. Thomson's patent had turned up and all Dunlop could claim was the application of an existing invention to cycles—and that was not patentable. Anyone was allowed to make and sell air tires. This seemed disastrous for the Pneumatic Tyre Company, which was built solely on the strength of Dunlop's patents. But they found a narrow escape. Many inventors had been attracted by the Dunlop air tire as the basis for patent modifications. C. K. Welch patented a new way of mounting the rubber cover of the inner air tube to the wheel rim. He specified what became known as a "wired on" cover. The cover had inextensible wires molded into its edges, which slipped over the wheel rim and were then pressed into ledges at the inner side of the wheel rim by the inflated air tube (Welch, 1890). Thus no cementing was needed and the air tire was readily detachable. Two other patents, by W. E. Bartlett, came close to Welch's patent. They applied to mounting solid tires molded to fit into clinches on the wheel's rim (Bartlett, 1890a,b). Du Cros bought these three patents and the new mounting his engineers made on the basis of these modifications subsequently proved to represent substantial improvements. Now the tires could be mounted by the bicycle producers themselves, and the expensive transportation of wheels was no longer needed. Moreover, it was rather easy for the cyclist to detach and refit the tire, which was especially important for repairing punctures. It was on the basis of these three patents that the Pneumatic Tyre Company prospered after all. Numerous infringements had to be fought by Du Cros and Dunlop, but gradually all competitors were either forced by legal action to stop their business or their companies died a natural death (Grew, 1921: 56). In 1895 the Dunlop Pneumatic Tyre Co. Ltd. was founded with capital of £5,000,000 (Doorman, 1947: 506). The histories of Thomson and Dunlop thus provide, paradoxically, an illustration of the adage "few patentees grow wealthy." Thomson did not see any commercial return from his patent, although it effectively covered the most crucial aspects of the air tire. Dunlop's air tire enterprise prospered, but without his own original patents having been granted.

In France the firm E. E. Michelin held a patent on an air tire with no outer cover, which could be mounted rather easily. However, in Europe this tire lost popularity to Dunlop's "wired-on" tires. Only in the United States did the Michelin tire hold out for some years.[71]

The competition between the air tire companies, prior to the settlement of the patent controversies, was fierce and greatly stimulated the popularity and promotional importance of racing. Previously the bicycle maker bought his solid or cushion rubber tires from manufacturers who limited their advertising to occasional announcements in the trade journals and did not approach the general public directly. Not so the pneumatic tire producers, who started to announce loudly every win on a machine fitted with their product. Now men were racing to advertise tires as much as to promote the bicycles themselves.

Although the air tire was taking over quite effectively (see table 2.1), the vibration problem had not completely been solved. In 1896, for example, new spring frames were still being exhibited. The "New Whippet" bicycle, incorporating a spring frame, was produced until the late 1890s. That this bicycle was not designed by an eccentric engineer, loving old-fashioned technology and fearing progress, is demonstrated by the fact that this machine also introduced some of the most innovative

Table 2.1

Percentages of exhibits of three types of tires in Britain, from 1890 to 1894

	1890	1891 (begin)	1891 (end)	1892	1893	1894
Solid	98.6	29.1	16.6	4.0	3.1	0.4
Cushion	0.06	54.2	32.2	14.9	14.7	3.3
Pneumatic	1.2	14.0	39.7	65.5	69.3	89.5

Source: *Encyclopedia Britannica.*

cycle accessories of the time, such as the free wheel, rim brakes, and a four-speed changeable gear (Caunter, 1958: 19). But the spring frame was becoming more and more obsolete and soon did not form a normal part of the pattern of the low-wheeled Safety bicycle, which was slowly becoming dominant.

2.9 Closure and Stabilization

In this third methodological intermezzo, I will discuss the last elements of the social constructivist descriptive model: the concepts of "closure" and "stabilization" of an artifact. It is with these concepts that we will clean up the sociologist's desk, littered with artifacts after the sociological demonstration of an artifact's interpretative flexibility. It is with these concepts that, after having carried out the sociological deconstruction, we will now trace its social construction.

For Dunlop and the other developers of the air tire, the tire originally had the meaning of a solution to the vibration problem, in other words, the air tire was an antivibration device. In the first advertisement, which appeared in a weekly cycle journal in Dublin in December 1888, the only claim made for the new pneumatic tire was that it made "vibration impossible."[72] However, the group of sporting cyclists riding their high-wheelers did not consider vibration to be a problem at all. Vibration presented a problem to the (potential) users of the low-wheeled bicycle only. Three important social groups were therefore opposed to the air tire; for these relevant social groups, the air tire did not work. But then the air tire was mounted on a racing bicycle, and another artifact was constructed. When the tire was used at the racing track for the first time, its entry was met with laughter. As I have described, this derision was quickly silenced by the sweeping victory realized on the new tire. Very soon handicappers had to give cyclists on high-wheelers a considerable start if riders on air-tired low-wheelers entered the race. After a short period no racer with any ambition bothered to compete on anything else. What had happened? By two important groups, the sporting cyclists and the general public, another artifact had been constructed: a high-speed tire.[73]

We thus have deconstructed the air tire into an antivibration tire and a high-speed tire, and demonstrated its interpretative flexibility. Now the question is: How did these two artifacts develop further? The tire company spared no efforts to develop the high-speed tire. They sponsored cycle racing, arranged training facilities under a competent trainer, and organized a regiment of professional racing teams with multiple machines.[74] Thus they succeeded in redefining the key problem for which the artifact was meant to provide a solution—now it solved the low-speed problem, rather than the vibration problem.[75] It is by no means self-evident that this should have been the outcome of the trial; enabling high speed is not an unambiguous, intrinsic property of the air tire that could dictate the course of events. On the contrary, taking for a moment the ahistorical viewpoint of an engineer, I find it very unlikely that it was the pneumatic tire that tipped the scales for the Du Cros brothers. Probably more influential were other differences between the high-wheeled Ordinaries and the low-wheeled bicycles with air tires: the chain drive on the latter and the high wind resistance on the former.[76] Thus the artifact "high-speed air tire" was socially constructed.

This social construction of an artifact is the outcome of two combined processes, closure and stabilization. These actually are two aspects of the same process, but for analytical purposes I will present them separately and only at the end of this section indicate that they are two sides of the same coin. The concept of closure relates to the interpretative flexibility argument, and is analogous to the discussion of closure of scientific controversies in recent social studies of science. The concept of stabilization is grounded in a critical evaluation of the naive invention-as-an-act-of-genius approach to the study of technology and draws on work in linguistics and recent laboratory studies in the sociology of science. Stabilization can most easily be introduced by analyzing the intragroup development of artifacts, while closure is primarily relevant to an intergroup analysis. If the closure concept has a primarily social interactionist origin, the stabilization concept is colored more by semiotics.[77]

Let me start a discussion of closure by briefly reviewing the analogous issue in controversy studies in the sociology of scientific knowledge.[78] When a scientific controversy is closed by the participants reaching consensus, scientific facts are created. This consensus means that the interpretative flexibility of, for example, an observation statement disappears, and from then on only one interpretation is accepted by all. Such a closure is not gratuitous, but has far-reaching consequences: it restructures the participants' world. History is rewritten after such a closure, and it is difficult to recapture the factual flexibility as it existed prior to the ending of the controversy. On the other hand, it is in principle always possible—although in practice very difficult—to reopen up a controversy once closure is reached.

Several closure mechanisms have been identified. For example, in the case of the "rhetorical closure mechanism," there is a "crucial experiment" or a "knock-down argument" that has the effect of closing a controversy without being completely convincing to the core set of scientists; its effect is based on the appeal that the experimental results or arguments have on a wider and less expert audience.[79] The case of the air tire is an example of the "redefinition of problem" closure mechanism (Pinch and Bijker, 1984). Additional closure mechanisms have been identified in other case studies (Beder, 1991; Misa, 1992).

Let us return to the analysis of technology and the case of the Macho Bicycle versus the Unsafe Bicycle. There, an example of rhetorical closure could almost be seen—if it had succeeded. One producer tried to make the case for his Macho Bicycle by claiming its "absolute safety": "Bicyclists! Why risk your limbs and lives on high Machines when for road work a 40 inch or 42 inch 'Facile' gives all the advantages of the other, together with almost absolute safety."[80] If this producer had succeeded, the Unsafe Bicycle would have become obsolete. This is an example of (failed) "rhetorical closure," for the engineers still considered the height of the bicycle and the forward position of the rider a safety problem.

Closure, in the analysis of technology, means that the interpretative flexibility of an artifact diminishes. Consensus among the different relevant social groups about the dominant meaning of an artifact emerges and the "pluralism of artifacts" decreases.

I will now turn to the concept of stabilization, which underscores the observation that technical change cannot be the result of a momentous act of the heroic inventor. Here the focus will be on the development of an artifact within one relevant social group. Employing the descriptive model, we should be able to trace growing and diminishing degrees of stabilization of the different artifacts. In principle the degree of stabilization will be different in different social groups.

This process of increasing or decreasing stabilization can be traced by using an established type of rhetorical analysis first employed in science studies by Latour and Woolgar (1979). They showed that in the construction of scientific facts "modalities" are attached or withdrawn from statements about facts, thus connoting the degree of stabilization of that fact. Thus the statements: "The experimenters claim to show the existence of *X*," "The experiments show the existence of *X*" and "*X* exists" exhibit progressively fewer modalities and thereby show progressively greater degrees of stabilization of *X*.[81] In the study of technical cases, similar varieties can be seen in the number of definitions, specifications, and elucidations attached to statements about the artifact. Of course, as Latour and Woolgar also observed, there is a methodological problem in this use of language as a medium through which to trace stabilization. The need to add definitions and elucidations to be able to communicate about an artifact depends on more than the degree of stabilization of that artifact in that social group; it will at least depend as well on the context in which the statement is used (e.g., a research paper, a patent, or a handbook). When, however, we take one relatively stable social group and analyze a communication situation that is relatively constant over time, this problem seems negligible. To trace the Safety bicycle's stabilization process, I will sketch how the bicycle was described within the social group of cycle engineers in one specific communication channel, their journal *The Engineer*. Thus the "invention" of the Safety bicycle will be depicted not as an isolated event (for example, in 1884), but as an eighteen-year process (1879–1897).

How are the processes of closure and stabilization related? In my analysis of the concept of closure I implicitly focused on the meanings attributed by different relevant social groups to an artifact. In contrast, for the analysis of stabilization, the focus was on the development of the artifact itself within one relevant social group, in terms of the modalities used in its descriptions.

Closure leads to a decrease of interpretative flexibility—to one artifact becoming dominant and others ceasing to exist. As part of the same movement, the dominant artifact will develop an increasing degree of stabilization within one (and possibly more) relevant social groups.

It is important to recognize that the process of closure is almost irreversible—almost, but not completely. It is now difficult to see the Ordinary bicycle as anything other than a very unsafe machine that is extremely difficult to ride. Trying to envisage the Ordinary as the artifact it was for its contemporaneous users seems to require not only the mental gymnastics of interpretative flexibility, but physical skills as well.[82] Thus it could be said in 1889 that "it must be understood that the safety bicycle is far more difficult to ride than the one of the ordinary type."[83] Evidently closure involves more than a psychological gestalt switch. The irreversibility aspect of closure may seem to induce a static element in the description of technical change. This is not necessary, however, because we have the stabilization process to highlight the continuous character of technical change. The combination of stabilization and closure processes makes it understandable that technical change is a continuous process, although not one that occurs at equal rates at every point in time; it is more like a punctuated evolution.[84] In this way the concepts "closure" and "stabilization" are especially important in making the SCOT framework meet the change/continuity requirement introduced in the first chapter.

2.10 The Safety Bicycle

The pneumatic tire made the scales tip in favor of the safety bicycle. As Gwen Raverat, a granddaughter of Charles Darwin, remembered in her autobiographical sketches:

> Then, one day after lunch, my father said he had just seen a new kind of tyre, filled up with air, and he thought it might be a success. And soon after that everyone had bicycles, ladies and all. (Raverat, 1952: 238)

The high-wheeled bicycle was less frequently called Ordinary, and received instead the nickname of Penny-farthing. One of the last Penny-farthings was a racing machine designed by Rudge-Whitworth in 1892. It had air tires, which shows to how large an extent the air tire was identified with making high speed possible, instead of (only) with serving as an antivibration device. The chain drive of the low-wheeler was thought to waste power; hence the designers' efforts to further develop the scheme of the high-wheeled bicycle (Caunter, 1958: 18).

The victory of the safety over the Penny-farthing did not come about without active opposition of the proponents of the high-wheeler. The tale of Franz Schröder's fight against the low-wheeler is only an anecdote, but it typifies the views held by many confirmed Ordinary riders. When the first low-wheeled Rover appeared in the small town of Coburg, Schröder planned a demonstration ride together with his wife on two high-wheelers. When a woman could ride an Ordinary bicycle, he reasoned, there would be no reason to opt for the low-wheeler. By this time, Schröder also had a commercial interest, as he had acquired the dealership of Bayliss, Thomas & Co. and was now trying to sell Ordinaries. He "publicly" announced his Sunday tour through the barber shop conversation network, and when the Schröders departed, many faces peeped through the curtains, more horrified than impressed by such an indecent sight (Timm, 1984: 120–122). The result was disappointing, and Schröder's competitor sold his Safeties. Then it was tried, also in Coburg, to end the controversy between proponents of the low-wheeled and the high-wheeled bicycles through races. In the first race, for which the bets were 1:14 in favor of Schröder on his high-wheeler, he won convincingly. The next week he sold three high-wheelers. Then he started to write a book in which he argued that cycling led the way to "Cyclisation": the high-wheeler obliged its rider to watch the road carefully; all brooding disappeared and instead the senses of sight, hearing, and touch were sharpened. Only riding an Ordinary bicycle really was bicycling. The Ordinary was a "sense-sharpening machine" that constituted the essential feeling of life: moving, with great pleasure, but continuously in danger of falling. And finally, it was the ultimate aesthetic experience: "still und bewegt" (andante con moto) (Timm, 1984: 147).

The Ordinary riders were not considered conservative. On the contrary, when the bicycle society in Coburg split into a high-wheeler and a low-wheeler society, the adepts of the Ordinary were reproached for being Jakobiner and revolutionary anarchists. This splitting of the Coburg bicycle society indicated the beginning of the end for the high-wheeler in that small town. As the quote from Schröder's book notes indicated, he did not value speed most prominently. Nevertheless, the rhetorical power of the speed argument was effective for others, and the final blow against the high-wheeled bicycle in Coburg was delivered in a second race, for which the Safety dealer had hired a semiprofessional racer and a lightweight Peugeot racing bicycle on pneumatic tires. Now the bets were 1:12 against Schröder. When Schröder finally made it to the finish line, the public had left and the rainy Schlossplatz was empty but for his wife and his competitor, who had arrived hours earlier. No Penny-farthing was ever sold in Coburg after that.

Development of the Design of the Safety Bicycle

With the air tire, the low-wheeled bicycle was gaining a decisive advantage over the high-wheeled Penny-farthing. But this does not mean that a basic design scheme of the low-wheeler had been settled. Developments in designing the driving mechanism and the bicycle frame indicate how such a basic scheme gradually emerged. I will follow this in some detail, partly because of its interest for bicycle history per se, but also to give a background for better understanding of the safety's stabilization.

Once the scheme of the Ordinary with its direct drive was abandoned, a great variety of other driving mechanisms were designed. Forms of transmission included the lever (Coventry tricycle), epicycle gears,[85] independent ratchet (Star), pivoted lever (Facile), steel band (Otto dicycle), and front and rear chain drives. One of the debates centered on the best kind of movement for the rider's feet: up-and-down versus rotary action. However, low-wheeled bicycles had never been equipped with lever mechanisms, and after the Safety Ordinaries became obsolete, rotary action became standard. Within the domain of rotary-action drives, two different mechanisms continue to exist: the chain drive and the shaft drive (the latter now used only in motorcycles).

The chain drive has a long history. First in the form of a simple pin or stud chain, then as a roller chain, it was extensively used in driving textile machinery, for example.[86] In 1880 the bush roller chain was patented by Hans Renold, and was further improved by patents in 1891 and 1899. Here, the hollow bushes spread the load over the entire length of the rollers. A point that required particular attention was a device for adjusting the tension of the chain. At the Stanley Exhibition of 1890, the washer-and-threaded-fang device, still used today, was presented for the first time (Engineer, 1890b: 139–140). The chain drive had several problems. One was that it could not be applied to the middle of the axles, so that there was an asymmetric pull on the machine. A possible solution was to use two chains, one on each side of the bicycle, but that would amplify other problems. A second problem was that chains were inevitably affected by the dust and mud splashing up from the road. This created extra wear if they were not cleaned and lubricated frequently. Third, the chain tended to damage clothes, as "there is a growing tendency, especially among the more fashionable devotees, to ride in ordinary walking costume, and this involves damage to the nether garments by reason of their entanglement with the chain" (Engineer, 1897c: 569). One way to try to solve the last two problems was to design effective protective chain casings. A solution to all three problems was the shaft drive.

Already in 1882 a shaft and bevel gear drive designed by S. Miller (1882) was used on a tricycle and on several bicycles such as the Humber & Goddard, the Columbia, and the Acatène shaft-driven bicycles.[87] One of the disadvantages of the shaft drive was that it had relatively high friction. Various designers sought to overcome this problem through improved gearing.[88] The chainless drives were valued for their noiseless running, but it required more accurate workmanship to manufacture them than the chain drive, and consequently their price was higher (Engineer, 1898: 514). With the development of an adequate chain casing, two important benefits of the shaft-driven bicycle over the chain-driven machine had disappeared, and after 1900 almost all bicycles were driven by chain.

Some of the basic frame forms have been described already. Of these, the cross frame and the diamond frame were preponderant. In 1888 a synthesis of the two schemes was proposed, as reported by *The Engineer* (1888a: 118): "Of the two types of frame, the cross frame and the diamond frame seem to be in equal demand, while another distinct type seems to be coming into favour as a combination of the strong points of the two others." The general problem of frame design is to build a structure in which applied forces are taken up as tension and stress, not as torsion or bending. Such is the principle of the "space frame," used in bridges, tower cranes, and motorcars. In bicycle frames this is not feasible, and both the diamond frame and the cross frame offer partial solutions to the problem. In the diamond frame the main forces are taken as direct stress, even though there are bending forces in the front fork and torsion forces in the entire frame as the rider exerts pressure on the pedals. (On the high-wheeled Ordinary, the rider felt these forces through the handlebar.) The stiffness and strength of the cross frame relies almost entirely on the strength of the main tube running between front fork and rear wheel (see figure 2.25). One possible improvement within this scheme is to enlarge the cross section of the main tube. This

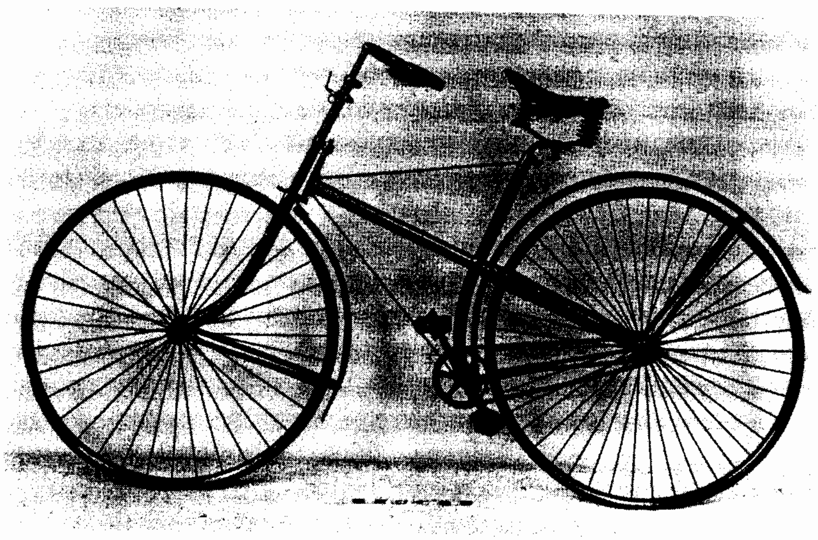

Figure 2.25
This bicycle of 1886 has a cross frame, which was later strengthened by adding two stays as shown in this photo. The wheels were mounted with cushion tires. Photograph courtesy of the Trustees of the Science Museum, London.

idea guided the design of some recent motorized bicycles, where the gasoline tank was incorporated in the main tube. The other possible improvement is to add further frame members, thus leaving the pure crossbar principle by making a partial triangulation. When adding such further bars or stays, the obvious advantage of the cross frame—that it was equally suitable for men and skirt-wearing women—disappeared of course.

But even with stays, the cross frame came to be considered less stiff than the diamond frame: "Makers are at last grasping the advantage to be derived from staying the frames, and few machines with the cross frame are exhibited without any stays. The most popular type of frame appears to be the diamond-shaped" (Engineer, 1889: 157–158). It was even asked whether the perfect diamond frame would not be too stiff, "thereby throwing an increased amount of vibration on the joints and connections" (Engineer, 1889: 158). By 1890, the diamond frame was evidently most popular (Engineer, 1890a: 107), but there was still discussion about what constituted the best diamond form. On the Humber of 1890, with straight tubes, a 15,000-mile journey across Europe, Asia, and the Americas was accomplished between 1890 and 1903 (Caunter, 1955: 37). This certainly provided an argument in favor of the frame with straight tubes. By 1895 this diamond frame, then known as the Humber pattern, was "the favourite the world over" (Engineer, 1896: 54), and by 1897, "finality appears to have been nearly reached in the design of frames" (Engineer, 1897c: 569).

Many more details were developed in the late 1890s, such as improved rim and hub brakes, the three-speed gear, integral butt-ended tubes, and "all-steel" frames. Nevertheless, the modern bicycle can be said to have existed since about 1897. It consisted of a diamond frame with vertical bar between saddle support and bracket, equal-sized wheels, and a chain drive on the rear wheel. Its stabilization among the relevant social group of bicycle engineers had taken eighteen years. At the beginning of this period one did not see the safety bicycle, but a wide range of bi- and tricycles and among those a rather ugly crocodile-like bicycle with a relatively low front wheel and rear chain drive (Lawson's Bicyclette). In an exhibition report in *The Engineer* in 1888, the names "ordinary bicycle" and "rear-driven safety bicycle" are used to described the various models on display. Of the "rear-driven safety bicycles" it is specified that two different types of frame, the cross frame and the diamond frame, are in equal demand (Engineer, 1888a: 118). Soon after that, the label for the low-wheeled machine is condensed to "R.D. safety bicycle" (Engineer, 1888b: 131) and another year later it is sufficiently unambiguous to call the machine a "safety bicycle" (Engineer, 1889: 158). By 1895 the stabilization seems to have been so complete as to enable *The Engineer*'s correspondent to merely use the label "bicycle" when describing the low-wheeled machine with rear-driving chains and diamond frame (Engineer, 1895: 54). This development is nicely summed up by one of *The Engineer*'s correspondents in 1897:

> The processes of natural selection, and the survival of the fittest, have given the world the diamond frame, the rear driver, the socket steering head, and so on, and the differences between the machines of any half-dozen makers are so small that only the expert can detect them. . . . [T]he modern bicycle has been in a way crystallized out of a solution of inventors' patent devices and manufacturing processes, and little room is left . . . for change or improvement. (Engineer, 1897b: 492)

By this time, the word "safety bicycle" denoted unambiguously a low-wheeled bicycle with rear chain drive, diamond frame, and air tires. As a result of the stabilization of the artifact after 1898, one did not need to specify these details: they were part of the taken-for-granted reality of the safety bicycle.

Groups of Users

As the design of the safety bicycle stabilized, so did its use among various social groups. The status of bicyclists in Britain rose abruptly when an act of Parliament conceded that the bicycle was a carriage and therefore entitled to a place on the roads, provided a bell was rung continuously while the machine was in motion (Woodforde, 1970: 3–4). The number of cyclists grew steadily. Cycle clubs proliferated: in 1880 there were more than two hundred cycle clubs, of which seventy were based in London (Marshman, 1971). The Cyclists' Touring Club, founded in 1883, had over 20,000 members in 1886. Based on the estimate that only 2.5 percent of cyclists were members of this club (Woodforde 1970), there were 800,000 cyclists in Britain in 1886, and in 1895 more than 1.5 million. The increasing number of bicyclists formed a pressure group arguing for better road maintenance, and between 1890 and 1902 the expenditure on the main roads of England and Wales increased by 85 percent, perhaps partly due to this pressure (Woodforde, 1970: 3).

With the low-wheeled safety, more social groups started to use the bicycle. Now, not only the young and athletic rode bicycles, but "bicycling became the smart thing in Society, and the lords and ladies had their pictures in the papers, riding along in the park, in straw boater hats" (Raverat, 1952: 238). The bicycle became the accepted conveyance for getting to social and business engagements, in addition to its use for sport, racing, touring, and circulating through the parks. In fashionable circles, the bicycle became so much an object to be cherished that it was not kept in the stables or outbuildings, but housed prominently in the halls of Chelsea House, Grosvenor House, and the like. Many of these bicycles were hand-painted in bright colors.[89] As Gwen Raverat remembered:

> How my father did adore those bicycles! Such beautiful machines! They were as carefully tended as if they had been alive; every speck of dust or wet was wiped from them as soon as we came back from a ride; and at night they were all brought into the house. (Raverat, 1952: 240)

The low-wheeled Safety at last paved the way for women bicycling as well. As previously mentioned, riding a high-wheeler was considered utterly improper for a woman. But with the low-wheeled safety, the two main problems presented to women by the Ordinary bicycle, indecency and lack of safety, were solved. Also in this part of cycle history, the aristocracy took the lead.[90] Gwen Raverat remembers how her mother was probably the first woman in Cambridge to have a bicycle. Then

> bicycles gradually became the chief vehicles for ladies paying calls. They would even tuck up their trains and ride out to dinner on them. One summer evening my parents rode ten miles to dine at Six Mile Bottom; their evening clothes were arranged in cases on the handlebars; for of course you couldn't possibly dine without dressing. (Raverat, 1952: 86)

In the 1890 cycle shows an increased number of ladies' bicycles were exhibited, and it was concluded that bicycling "was becoming popular with the weaker sex" (Engineer, 1890a: 108). This trend continued, and in a report on the 1896 cycle shows, a very large number of machines for female riders was again observed (Engineer, 1896: 54). The main difference between these models and the machines for men was the absence of the top bar of the diamond frame, and a great variety of designs were tried to solve the resulting need to stiffening the frame.

Appropriate bicycle clothing became even more of an issue than it had been before, when women were riding only tricycles. Gwen Raverat remembered:

> We were then promoted to wearing baggy knickerbockers under our frocks, and over our white frilly drawers. We thought this horridly improper, but rather grand; and when a lady (whom I didn't like anyhow) asked me, privately, to lift up my frock so that she might see the strange garments underneath, I thought what a dirty mind she had. I only once saw a woman (not, of course, a lady) in real bloomers. (Raverat, 1952: 238)

The "bloomers" referred to by Raverat were an American invention of the 1850s, consisting of Turkish pantaloons with a knee-length skirt. They were named after Amelia Bloomer, who advocated them in her magazine *Lily* (Palmer, 1958: 98). As Raverat's comments suggest, bloomers were not accepted in Britain as appropriate cycling dress. The only practical outfit that could meet with some degree of approval was the "rational dress," which had originated on the continent around 1893. It consisted of knickerbockers, long leggings, and a coat that was long enough to look feminine but would not interfere with the bicyclist's movements. But for the Mr. Hoopdrivers of the world, even this dress presented a frightful sight. When for the first time his bicycle route intersected that of the Lady in Grey: "Strange doubts possessed him as to the nature of her nether costume.... And the things were—yes!—rationals! Suddenly an impulse to bolt from the situation became clamorous" (Wells, 1896: 20–21). This sight was such an attack on his emotional and physical equilibrium that, through a rapid and complex series of maneuvers, he ended up sitting on the gravel with feet entangled in his machine.

Many were the discussions in newspaper and cycling journal columns, and the case for rational dress was even fought in court. In 1898 Lady Harberton, founder and president of the Rational Dress Society, was refused service in a coffee room. The proprietor showed her into a dirty public bar where men usually drank alone. Harberton claimed the legal right to be served and took the proprietor to court. The defense argued that there had been no discrimination on the grounds of Lady Harberton's being improperly dressed. The judge upheld that defense, but nevertheless the case played a symbolic role in the fight for women's independence and emancipation.[91] Before the end of the nineteenth century, women bicyclists and their rational dress were to be seen in the remotest parts of Britain.

Other groups became interested in the bicycle as well. The postal service, for example, made extensive use of bicycles and tricycles in the collection and delivery of letters and parcels. The military also became increasingly interested, especially stimulated by the Boer War in South Africa (1899) in which the British army used bicycles on a large scale. Several bicycles were specifically designed for use in active service. Some designers offered lightweight folding bicycles, and others incorporated a gun almost as an integral part of the frame. Substantially similar bicycles were used in the First World War.

Bicycle Industry

Since the beginning of the cycle industry, local blacksmiths and mechanics have participated in constructing small numbers of bicycles to order. The dominance of the safety bicycle did not change this situation. Paradoxically, the standardization of the diamond frame had two opposite effects on industry: it further enhanced mass production, and it strengthened the position of those small workshops.

A considerable number of local bicycle makers could offer a "homemade" product to the residents of their small village at a price somewhat lower than that of factory-produced bicycles because of their lower overhead costs. Some large companies had specialized in the manufacture of standardized components, delivering them to both bicycle factories and local workshops. Thus three classes of machines could be distinguished. First, there were the mass-produced bicycles made by bicycle factories. Only the largest of these factories manufactured all components themselves; most of them had contracted out the manufacture of saddles, tires, and the like. Second, there were bicycles made by local workshops, constructed from proprietary components made by specialized firms. And the third class of bicycles, made by special departments of factories as well as by small workshops, was known as "de luxe" machines, produced without much regard for costs (Caunter, 1955: 43–44).

The dominance of the safety bicycle further stimulated the mass production of bicycles, which had begun in the days of the Ordinary. In the U.S. bicycle industry the manufacturing of interchangeable parts received more attention than in Britain (Hounshell, 1984: 193). The U.S. industry boomed,[92] and it engaged the British and industry in a struggle for the cycle business in all the markets of the world (Engineer, 1897a: 403). The British cycle industry was rather surprised at the growing international competition, for example in the case of a Dutch bicycle exhibited at the cycle show: "This, by the way, is the first time a firm of foreign manufacturers has exhibited at this annual exhibition, and Holland is certainly the last country in the world from which we expected competition" (Engineer, 1890b: 138). Apart from the United States, the rest of the world was considered a kind of industrial backwater.[93]

Chiefly because of the Safety bicycle, a cycling boom occurred in Britain 1895–1896. The increased demand could not be met by the existing manufacturers, and financiers and entrepreneurs were attracted to the industry. Some of the larger and better-known firms were purchased by these financiers and refloated for enormous sums, far above their previous value.[94] Even a shipbuilding company was reported to enter the cycle trade (Engineer, 1897a: 403). The unprecedented demand for bicycles proved to be a little unwarranted, as most dealers ordered more bicycles than they needed because they thought that only in that way they would obtain the required number in time. When the cycle season passed, many orders were cancelled. As a result of the floatations, many companies suffered overcapitalization. Large amounts had been paid for good will, patents, and other nontangibles. In 1896–1897, a great cycle slump swept over Britain (Grew, 1921: 71–72). Two or three lean years followed, ending only when the industry started to manufacture motorcycles and cars on a larger scale.

2.11 Conclusion

The leading historical question in this chapter is: How can we understand the role of the high-wheeled Ordinary bicycle in relation to its low-wheeled ancestors and successors? In setting out the problem, I suggested that this was a technical detour in bicycle history. The technologies needed to turn the 1860 low-wheelers into 1880 low-wheelers, such as chain and gear drives, were already available in the 1860s. This term "detour," however, turned out to be a misnomer. To use that term, one should assume that the bicycles of the 1880s were unambiguously better than previous artifacts and that every development that did not lead directly to this final result must be an aberration, a detour from the right path. I have shown, however, that the Ordinary bicycle can be interpreted as having been two things at the same time: a comfortable, classy, well-working artifact, and a dangerous, accident-prone, and thus nonworking machine.

The central conceptual program for this chapter necessitated the development of a descriptive model; such a model, I argued in chapter 1, should allow us to undertake case studies whose descriptions are "thick" enough to allow us to grasp the complexity of technical development, while still allowing for intercase comparisons. Such comparisons would enable us to make generalizations on the basis of several case studies, thus working toward a theory of sociotechnical change. For such a theory I formulated four requirements (see table 1.1).

To address these two issue—one historical and particular and the other theoretical—I used the same structure as for the book as a whole

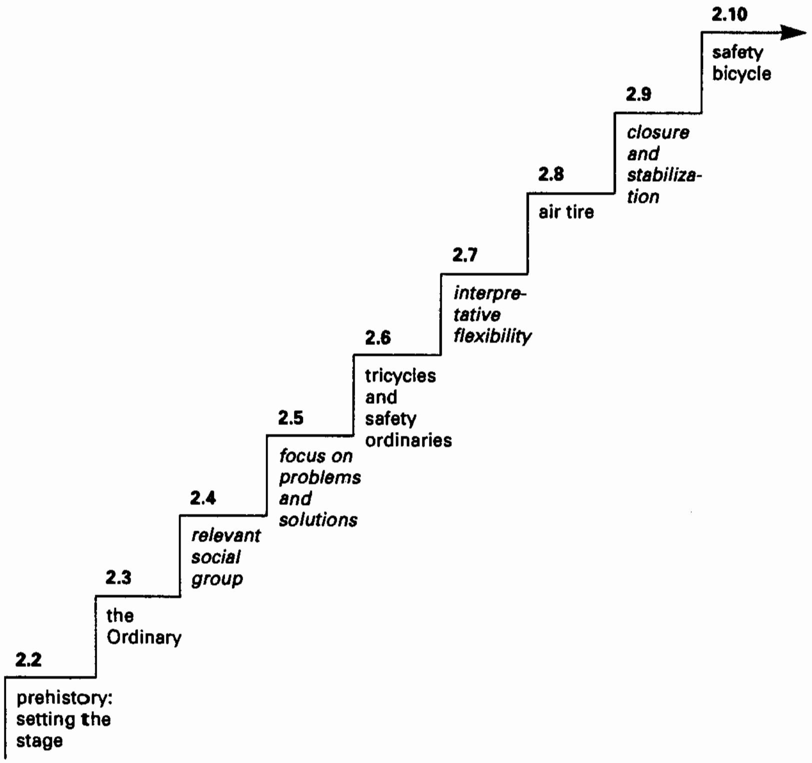

Figure 2.26
The chapter follows a staircase-like argument.

(see figure 2.26). We moved along the chapter as if climbing a staircase, each step taking us a little higher and serving as a bridge to the next. On each step, different elements were introduced that were carried along and put to use on later steps. Thus I started on the ground floor with a sketch of the prehistory of the bicycle, merely setting the stage. The first step then provided a detailed history of the early stages of the Ordinary's history. Looking around in Coventry, we saw how the first bicycle producers established themselves, building on existing engineering practice and helped by the particular economic circumstances of the time. We saw Hillman and Starley make their Ariel and launch it with the first record-setting bicycle ride. Then we followed the development of the high-wheeled bicycle by describing its users, the "men of means and nerve," as well as those who could or would not use the Ordinary. I tried to do this in such a way, by providing enough empirical detail on the

social groups involved, that we could reach the next step. In this step the concept of "relevant social group" was introduced. The central argument here was that groups relevant for the actors are also relevant for the analyst. This suggested the next step: to describe the "technical content" of artifacts through the eyes of the relevant social groups. To jump to that step, however, one small half-step was taken: I suggested that a focus on problems and solutions would be helpful in making such descriptions of artifacts. Armed with this conceptual apparatus, on the fifth step of the staircase we explored various solutions that were developed to solve the Ordinary's problems: tricycles, safety Ordinaries, and other radically different machines. This was a fairly straightforward step, once we had come as far as having relevant social groups and the focus on their problems and solutions as a vantage point. To move further proved difficult, however—how could we understand the coming of the safety bicycle? We climbed onto another step, where I introduced the concept of "interpretative flexibility." This was done by capitalizing on previous steps, especially on the decision to describe artifacts as constituted by relevant social groups. Armed with this concept, I deconstructed the air tire on the seventh step into an antivibration device and a speed-enhancing device, which resulted in a specific picture of the competition between safety bicycle and Ordinary. To reach the last level, the concepts of "closure" and "stabilization" were developed on the eighth step. Finally, having climbed all the way, we were able to give an account of the social construction of the safety bicycle.

Would it have been possible to tell this historical story without the conceptual intermezzi? Would it have been possible to develop the conceptual framework without the detailed empirical studies? I think not. Each step, empirical or conceptual, builds on the previous ones. Of course, each step also has its own small story to tell or little argument to develop; thus I have included some historical details just because they are interesting in terms of the history of the bicycle, and I have included some methodological discussions just because they link this framework to debates about a theoretical basis for technology studies. To stretch the metaphor to its limits: The staircase was not meant to be a narrow one that compelled you to move on, haunted by claustrophobia. I hope it was more of a flight of broad steps, on each of which you could move around and dwell for some time, depending on your specific interest in the views offered from there.

Where have we landed, on top of these stairs? How does the result compare to what was formulated as the aim of this book—to work toward a theory of sociotechnical change? The social constructivist descriptive model developed in this chapter meets at this moment two of the four requirements for a theory of sociotechnical change. The focus on relevant social groups and the concept of interpretative flexibility will ensure that the model meets the requirement of symmetry, while the concepts of closure and stabilization allow it to meet the change/continuity requirement. Thus the agenda is clear: We now want to use this descriptive model to generalize beyond the confines of one case. To do that, I shall now turn to the case of Bakelite. In the course of this case study I will introduce two further concepts that will help us meet the remaining requirements for a theory of technological development.

3

The Fourth Kingdom: The Social Construction of Bakelite

3.1 Introduction

"God said 'Let Baekeland be' and all was plastic." It is hardly possible to conceive of a technology that seems, at first blush, more contradictory to the social constructivist claims of chapter 2 than the invention of the first truly synthetic plastic by Leo Henricus Arthur Baekeland in 1907.[1] In standard accounts the search for a synthetic plastic material is described as lasting some forty years, a period during which numerous chemists failed, and that search climaxed with a creative flash in Baekeland's private laboratory.[2] Neither relevant social groups nor social construction processes figure in these accounts; it was, rather, the solitary individual Baekeland who created this invention, Bakelite. And what an individual! Baekeland's personalality and history have every element that would tempt the student of plastics to essay a biography of this "grand duke, wizard, and bohemian"[3] rather than a sociological analysis of the case.[4]

This will be the first aim of the chapter: to show that even in the case of "an individual inventor," a social constructivist analysis yields fruitful results. How can we understand the social construction of Bakelite despite the obvious individual achievements of its inventor? Or more specifically, how did Baekeland succeed in making a synthetic plastic after numerous chemists with access to the same resources had failed? To answer this question adequately, I will need to go beyond the descriptive model introduced in chapter 2. There, only the loose components of a social constructivist analysis of technology were provided; components that need to be combined into a coherent conceptual machinery before they can do real work. As one needs a diamond frame to make a bicycle out of the wheels, chain, steering mechanism, and saddle, so we need additional concepts to build a theory with the relevant social groups, interpretative flexibility, closure, and stabilization. It will prove crucial

5

Conclusion: The Politics of Sociotechnical Change

We have had stories and theories; now it is time for politics. I have presented this book as an effort to turn into a main route what had, for me, started out as a detour. In the last three chapters I have told three stories while building a conceptual framework that allowed us to generalize beyond the confines of those stories. At the outset I argued that this project could lead to a new way of thinking about political issues involving society, technology, and science. The detour would thus be turned into a main route.

I will start this chapter by summarizing the central features of that conceptual framework. This will result in a suggestion that, rather than formulating the central STS problematic in terms of relations among three distinct domains, we should direct our research and politics to a new unit of analysis: sociotechnical ensembles. I will then use the power conception introduced at the end of the last chapter to focus attention on the obduracy of such sociotechnical ensembles, and on what that obduracy might mean. Finally, I will argue that analyses such as these suggest strategies for creating a more democratic technological culture.

5.1 *Symmetry and Sociotechnology*

The Argument So Far

I have developed my theoretical argument in three steps. First, using the bicycle case, I posited a need to analyze technical change as a social process, introducing along the way the concepts of "relevant social groups" and "interpretative flexibility." Then, in reviewing the history of Bakelite, I tried to show the usefulness of introducing the idea of a "technological frame." Finally, in the fluorescent lamp case, I proposed a concept of "power" that would fit a constructivist analysis of technology and society.

The bicycle case showed that the development of technical designs cannot be explained solely by referring to the intrinsic properties of artifacts. For example, the high-wheeled Ordinary was at once a dangerous machine, prone to failure in the marketplace, *and* a well-working machine that allowed highly skilled physical exercise, resulting in a commercial success. I showed that this double character could be clarified by looking at the alternative bicycle designs through the meanings attributed to them by relevant social groups.

Exploring the roles of relevant social groups gave us a basis for understanding the concept of interpretative flexibility with respect to artifacts. As noted in chapter 2, this concept finds its philosophical and methodological underpinning in the principle of symmetry formulated by Bloor (1973, 1976) for the sociology of scientific knowledge. Bloor argued that a useful understanding of scientific knowledge systems can be gained only if investigators are impartial to the supposed truth or falsity of (scientific) beliefs. To analyze true and false claims symmetrically, they must apply the same conceptual apparatus to each. Thus, one would not say that a claim that is presently considered true is explained by its better correspondence with "Nature," nor would one argue that a claim that is presently considered false is explained by the "social circumstances" surrounding its conception. In each case, instead, one needs to approach "Nature" as what is to be explained, not as an element of the explanation. "Nature," in other words, is not the cause of scientific beliefs, but the result.[1]

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Pinch and Bijker (1984) argued that a similar principle should be applied to the analysis of technology—that we can understand technologies only if we analyze successful and unsuccessful machines symmetrically. Constructivist studies of technology strive not to consider the fact that a machine "works" as an explanation, but to address it as a subject requiring explanation. In this approach, machines "work" because they have been accepted by relevant social groups.[2]

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Having demonstrated the flexibility inherent in the interpretation of artifacts, I argued that our next step should be to map the process by which artifacts attain or fail to attain a stable interpretation. In this descriptive model, an artifact does not suddenly appear as the result of a singular act of heroic invention; instead, it is gradually constructed in the social interactions between and within relevant social groups. I introduced the term *closure* to describe the process by which interpretative flexibility decreases, leaving the meanings attributed to the artifact less and less ambiguous; this process can also be described in terms of the artifact reaching higher levels of *stabilization.*

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The concept of closure is also borrowed from the sociology of scientific knowledge, where it is used to describe how a scientific controversy ends with the emergence of consensus in the scientific community. Studies have shown that, following closure, the history of a controversy will be immediately rewritten. The interpretative flexibility of all scientific claims ceases to exist, and "Nature" is always invoked as the cause of consensus. Similarly, in the analysis of technology, closure results in one artifact—that is, one meaning as attributed by one social group—becoming dominant across all relevant social groups. In the case of the high-wheeled bicycle, closure resulted in the Macho Bicycle becoming obsolete and the Unsafe Bicycle becoming dominant. I did not trace in detail the latter's subsequent stabilization, but it can be appreciated from the change in names: The high-wheeled bicycle was no longer the Ordinary, but was henceforth nicknamed the Penny-farthing. After becoming dominant, the Unsafe Bicycle was actively improved and finally superseded by safer bicycles.

The process of closure is generally, but not absolutely, irreversible. Nowadays, for example, we find it strange that people once considered the Penny-farthing a well-working, comfortable machine. It is, in other words, very difficult to envisage the world as it existed before closure. This seeming irreversibility is, however, not exclusively, or even primarily, psychological, like a Gestalt that cannot be switched back. A specific technological frame, such as that of the solid tire or the air tire, comprises not only social-psychological elements, but artifacts, organizational constraints, and values as well. It is because of the heterogeneity of the frame that irreversibility is not absolute, and to formalize this idea I suggested that we consider *degrees* of stabilization. Each of the three stories revealed growing and diminishing degrees of stabilization. This perspective allowed us to understand the invention of the Safety Bicycle, for example, as an eighteen-year process (1879–1897), rather than as an isolated event occurring in 1884. We traced this process by noting the dropping of modalities in contemporaneous writings about the artifact.

In this way, the social-constructivist model highlights the contingency of technical development (by demonstrating the interpretative flexibility of artifacts), while describing how freedom of choice is narrowed by contextual constraints and alliances. Processes of social construction thus have a dual character: They include (almost) irreversible processes of closure, reflecting the steplike aspect of technical change, but they are also continuous between the steps, as indicated by changes in the degree of stabilization.

In chapter 3, I used the SCOT model to describe the development of Celluloid and Bakelite. Here again it proved difficult to label the inventor's work unambiguously as purely scientific, technical, social, or economic. Did Baekeland's condensation reaction result from a scientific fact (as he claimed himself)? Or was it the result of successful technical tinkering (as we may now think, knowing that Baekeland's theoretical explanation was superseded by macromolecular theories)? Or was it neither a scientific nor a technical accomplishment, but first of all a social and economic one—turning competitors into partners during patent litigation, and building networks of manufacturing companies that would use the new material? The explanatory concept of a technological frame, comprising knowledge, goals, and values as well as artifacts, was shown to mirror this heterogeneity.

After demonstrating the interpretative flexibility of the phenol-formaldehyde condensation product, I described the closure process and the subsequent social construction of Bakelite, during which the building up of a new technological frame could be seen. This constituted a new structural environment for further technical development. I must emphasize again that this structural interpretation is not meant to belittle the individual ingenuity, passion, and commitment of an inventor such as Baekeland. It does, however, place an individual's characteristics in a broader context, thereby rendering it subject to analysis by sociological as well as psychological tools.

In chapter 4, I used the technological frames of the utilities and the Mazda companies to explain the specific form of the high-intensity fluorescent lamp. I also showed how this artifact reshaped the technological frame, creating a new social order. This case introduced the distribution of *power* as a factor in shaping technology and society. The particular conception of power that I presented has two aspects: a semiotic aspect that emphasizes the importance of the fixation of an artifact's meanings, and a micropolitical aspect that focuses on the continuous interactions of relevant social groups in a technological frame. Power in this sense is not given a priori, nor is it an intrinsic property of actors; rather, it is itself an important explanandum. To explain a specific set of power relations—a semiotic power structure—and to reveal the micropolitics of power can thus be one cornerstone of an explanation of the development of a new order constituted by a particular combination of technology and society.

Beyond Technical Artifacts: From the Seamless Web to Sociotechnical Ensembles

In its crudest interpretation, the "seamless web" motif serves merely as a reminder that nontechnical factors are important for understanding the development of technology. It pulls us toward contextual approaches to the study of technology, as opposed to internalist analyses. A deeper interpretation, however, is that it is never clear a priori and independent of context whether a problem should be treated as technical or as social, and whether solutions should be sought in science, economics, or some other domain. Such an interpretation stresses that the activities of engineers and inventors are best described as heterogeneous system- or network-building, rather than as straightforward technical invention.[3] In my analysis I have taken an additional step beyond this interpretation by suggesting that it is not only engineers (even in their upgraded guise as system-builders or network-weavers) but all relevant social groups who contribute to the social construction of technology. In the case of the high-intensity fluorescent lamp, for example, the actual designers were not engineers at their drawing boards but managers at a business meeting.

Let us now take one further step and suggest a third interpretation of the seamless web. The "stuff" of the fluorescent lamp's invention was economics and politics as much as electricity and fluorescence. Let us call this stuff "sociotechnology." The relations I have analyzed in this book have been simultaneously social and technical. Purely social relations are to be found only in the imaginations of sociologists or among baboons,[4] and purely technical relations are to be found only in the wilder reaches of science fiction.[5] The technical is socially constructed, and the social is technically constructed. All stable ensembles are bound together as much by the technical as by the social. Social classes, occupational groups, firms, professions, machines—all are held in place by intimate social and technical links.[6]

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The move from the domain of technical artifacts plus social relations into the domain of sociotechnology can be linked to Michel Callon's (1986) principle of general symmetry, which expands Bloor's principle of symmetry. While Bloor's principle advocates that true and false beliefs (or, in the case of technology, working and failing machines) are to be explained in the same terms, Callon's principle of general symmetry states that the construction of science and technology and the construction of society should be explained in the same terms. This principle outlaws both technical reductionism (in which society is explained as an

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outgrowth of technical development) and social reductionism (in which the technical is explained as a by-product of the social).

Linked to this principle was a proposal that symmetrical roles be assigned to human and nonhuman actors. (See table 5.1 for a summary of the various concepts.)[7] This proposal has been the subject of a heated debate that potentially divides students of sociotechnology into two camps, one Anglo-Saxon and the other French.[8] For the former camp, it amounts to a heresy against the Winchian (1958) tradition in the social sciences to allow machines as actors into the story. For the latter camp, the analyses within Bloor's symmetry scheme are hardly more than internal accounts and do not provide insight into such crucial questions as the relation between micro events and macrosocietal developments.[9]

In my conception, the sociotechnical is not to be treated merely as a combination of social and technical factors. It is sui generis. Instead of technical artifacts, our unit of analysis is now the "sociotechnical ensemble."[10] Each time "machine" or "artifact" is written as shorthand for "sociotechnical ensemble," we should, in principle, be able to sketch the (socially) constructed character of that machine. Each time "social institution" is written as shorthand for "sociotechnical ensemble," we should be able to spell out the technical relations that go into stabilizing that institution. Society is not determined by technology, nor is technology determined by society. Both emerge as two sides of the sociotechnical coin during the construction processes of artifacts, facts, and relevant social groups.

How might this extension of the principle of symmetry affect our work? One possible reaction might be to avoid the complexity of this new sociotechnical world by refraining from theoretical explanations. Only narratives are to be made, only "how questions" to be answered; no models are to be conjectured, no "why questions" to be asked. Clearly, this is not the route I would advocate. Complexity, for me, simply implies a challenge to develop more adequate conceptual frameworks.[11] The theory of sociotechnical change that I am developing, for example, must mirror the heterogeneity of this sociotechnical "stuff" without resorting to just "adding up" the social and the technical.

One way to avoid the twin horns of social and technical reductionism is to introduce other differentiations between explanandum and explanans, between dependent and independent variables, between foreground and background—differentiations that are not based on the distinction between the social and the technical.[12] This is exactly what

Table 5.1
Summary of concepts employed in the principle of symmetry (Bloor, 1973, 1976; Pinch and Bijker, 1984) and the principle of general symmetry (Callon, 1986) (analogous concepts are grouped in horizontal rows)

Symmetry (Bloor on science)	Symmetry (Pinch and Bijker on technology)	General symmetry (Callon on sociotechnology)
Impartial to a statement being true or false.	Impartial to a machine being a success or failure.	Impartial to an actor being human or nonhuman.
Symmetrical with respect to explaining truth and falsity.	Symmetrical with respect to explaining success and failure.	Symmetrical with respect to explaining the social world and the technical world.
"Nature" is the result, not the cause, of a statement becoming a true fact.	"Working" is the result, not the cause, of a machine becoming a successful artifact.	The distinction between the technical and the social is the result, not the cause, of the stabilization of sociotechnical ensembles.

the concept of "technological frame" is meant to do. Its heterogeneity should allow us to distinguish foregrounds and backdrops other than the technical and the social (or vice versa).

As a first illustration, consider the configuration model below, which will allow us to model sociotechnical change by mapping it onto different configurations characterized in terms of technological frames and degrees of inclusion.

A Configuration Model

Using the concepts of "technological frame" and "inclusion," I will now iron some pleats into the seamless web of sociotechnology. In place of differences between the social and the technical, I will distinguish among alternative *configurations*. A second step will be to use this foregrounding and backgrounding to build an explanatory model, generalizing beyond individual case studies by identifying processes that occur in specific configurations, irrespective of the particular case.

As a first-order analysis, three different configurations can be distinguished. In the first, *no* clearly dominant technological frame guides the interactions; in the second, *one* technological frame is dominant; and in the third, *two or more* technological frames are important for understanding interactions involving the artifact under study. Each of these configurations is characterized by different processes of technical change.

The first configuration occurs when there is no single dominant group and there is, as a result, no effective set of vested interests. The early history of the bicycle provides an example. Although there were many social groups involved, it is hard to characterize any of them as dominating the field and structuring the identification of problems and the problem-solving strategies to be used. Under such circumstances, and if the necessary resources are available to a range of actors, there will be many different innovations.

In the second configuration, one dominant group is able to insist upon its definition of both problems and appropriate solutions. This is probably the most common configuration—"normal sociotechnology," to paraphrase Kuhn. The period between 1880 and 1920 in the development of (semi)synthetic plastics provides an example, with the Celluloid technological frame being dominant. Under such monopolistic circumstances, innovations tend to be conventional.

In the third configuration, when there are two or more entrenched groups with divergent technological frames, arguments that carry weight in one of the frames will carry little weight in the other. Under such circumstances, criteria external to the frames in question may become important as appeals are made to third parties.

Having characterized three different configurations, our next task is to specify which processes of sociotechnical change can be expected to occur in each configuration. Without being in any sense complete, I will discuss several possibilities, drawing on work by other scholars to demonstrate the generalizing and integrating power of the configuration model. What I will present is thus a demonstration of the feasibility of developing theoretical models along these lines, not a full-blooded and comprehensive model of sociotechnical change.

When there is no dominant technological frame, the range of variants that can be put forward to solve a problem is relatively unconstrained. The alternative sociotechnical ensembles that are generated will tend to be *radical*, in the sense that they differ substantially from the pattern laid down in any given frame. This would apply to all sociotechnical ensembles, or their elements. For technical innovations this situation has been well described by Hughes (1987), but similar observations can be made about social innovations.

In the case of the bicycle, for example, radically different technical variants were proposed around 1880 to solve the safety problem, but there were also efforts to make radical changes in other elements of the sociotechnical ensemble "Ordinary + macho aristocrat + excluded Victorian ladies." In the American "Star" (figure 2.19), the small steering wheel was positioned ahead of the high wheel; Lawson's Bicyclette (figure 2.20) had a chain drive on the smaller rear wheel. Women's clothing was designed differently to accommodate the technical constraints of the bicycle and also to make an emancipationist statement about women's societal position. Thus "radically different" means that all aspects of this sociotechnical ensemble were subject to variation. Hardly any detail of the bicycle was taken for granted—not even the number of wheels (tri- and quatro-cycles were constructed) or the method of foot propulsion (besides moving cranks in a circular motion, various lever devices were constructed, requiring a linear vertical motion of the feet). Hardly any detail of the nontechnical aspects of the ensemble was taken for granted either: sex or class of the cyclist, purpose of the cyclist, societal function, and status of bicycling.

One of the most important stabilization processes in a configuration without a clearly dominant social group and technological frame is *enrollment* (Callon and Law, 1982). This describes the process by which a social group propagates its variant of solution by drawing in other groups to support its sociotechnical ensemble. More than in the other configurations, the success of an innovation will here depend upon the formation of a new constituency—a set of relevant social groups that adopts the emerging technological frame.[13] One way to do this is by the mechanism of *problem redefinition* (Pinch and Bijker, 1987). If an artifact such as the air tire offers a solution to a problem that is not taken seriously by other important social groups, then the problem may be redefined in such a way that it does appeal to them. Thus the problem for which the air tire was originally considered to be a solution (vibration) was redefined into a speed problem. Because speed was important to the racing cyclists, they were now enrolled.

In the second configuration type, when one technological frame is dominant, it is fruitful to distinguish between actors with high and low inclusion. Engineers with a relatively high inclusion in the technological frame will be sensitive to *functional failure* (Constant, 1980) as an incentive to generate variants. A functional failure may occur when an artifact is used under new, more stringent conditions. Celluloid's flammability presented such a functional failure when its use was extended to other applications besides dentures, such as photographic film. Actors with a high inclusion in the technological frame are bound to generate relatively conventional inventions such as improvements, optimalizations, and adaptations (Hughes, 1987). Thus, a large part of the innovative effort of the celluloid producers was directed toward rendering celluloid less flammable by finding another solvent.

Actors with a relatively low inclusion in the technological frame interact to a smaller extent in terms of that frame. A consequence may be, as in the case of Baekeland, that such actors draw less on the standard problem-solving strategies of that frame. Another consequence could be that such actors identify other problems than would actors with high inclusion. For example, the identification of *presumptive anomalies* is typically done by engineers with a relatively low inclusion in a particular frame. A presumptive anomaly "occurs in technology, not when the conventional system fails in any absolute or objective sense, but when assumptions derived from science indicate either that under some future conditions the conventional system will fail (or function badly) or that a radically different system will do a much better job" (Constant, 1980: 15). Constant cites the example of aerodynamic theory in the 1920s, which suggested a future failure of the conventional piston engine/propeller system of aircraft propulsion. It suggested that proper streamlining would allow aircraft speeds to be increased at least twofold, but that the propeller would probably not function at the near-sonic speed that would result. The theory also suggested the feasibility of highly efficient gas turbines. My contention is that young, recently trained engineers are in an especially good position to recognize and react to presumptive anomalies: they are trained within the current technological frame but have low enough inclusion to question the basic assumptions of that frame.

In the third configuration, more than one technological frame is dominant. For example, around 1890 electricity distribution systems based on both direct and alternating current had been commercialized, sometimes in the same town (Hughes, 1983). The closure process in a configuration like this can be quite erratic, particularly in comparison with the first configuration. Arguments, criteria, and considerations that are valid in one technological frame will not carry much weight in the other frames. In such circumstances, it seems reasonable to expect that criteria external to all technological frames will play an important part in closure and stabilization. This often makes *rhetoric* a significant closure mechanism (Pinch and Bijker, 1987). (Of course, rhetoric may also be a factor in the second configuration.) Hughes (1983) described such a rhetorical move in the "battle of currents." In a public demonstration, a dog was exposed to direct current of various voltages with no ill effects and was then electrocuted by quick exposure to alternating current. The object of the demonstration was to persuade citizens that direct current was the safer alternative. As Hughes observes, often in such a "battle of the systems"—a competition between powerful, equally dominant social groups with respective technological frames—no one wins a total victory. *Amalgamation of vested interests* is the closure process that often occurs.[14] Innovations that allow amalgamation will be sought, and such innovations (the construction of the high-intensity fluorescent lamp is an example) are, so to speak, doubly conventional because they have to lodge within both technological frames.

The configuration model gives a crude explanation of some of the processes of sociotechnical change that can be observed, but it does not yet make the link to a politics of technology. That is our next goal.

5.2 *Toward a Politics of Sociotechnology*

The detour into academia that I described at the beginning of this book can turn into a main route in several different ways. First, travelers might forget that their initial interest in STS issues was politically motivated and simply continue on the highway of *institutionalized academic work.* It should be abundantly clear by this point that this is not the route I have had in mind.

A second route does turn back to political concerns, but for purposes that are allied to the interests of a specific social group. Stimulated by recent successes in academic science and technology studies, encouraged by the demand for instruments to solve policy problems, and facilitated by a no-nonsense culture that allows critical activists of the 1970s to become management consultants in the 1990s, this route leads toward science and technology *policy studies.* It is not unlikely that the insights gained in the detour so far will indeed allow the development of concrete policy instruments, and that these instruments will be useful within the technological frame of policymakers. The route toward technology policy is, however, also not the main route I want to pursue.

I would like to argue for a third route leading toward a *politics of technology.* This politics will deal with questions of value-ladenness, of emancipatory and oppressive potentials, of democratization, and of the embeddedness of technology in modern culture.[15] In other words, it will be concerned with questions about sociotechnical ensembles and the semiotics and micropolitics of power. Such a main route would take the much-quoted dictum of Langdon Winner (1980) that "artifacts have politics" and link it to the epistemological insights of recent studies of the sociology of scientific knowledge and to the theoretical and empirical work of constructivist studies of technology. The politics of technology in this sense will not yield the concrete policy instruments that the second route promises to produce. It will be emancipationist rather than instrumental, it will politicize technological choices rather than pacify them, and it will problematize rather than absolve.

My argument for a politics of technology involves three steps. First, I will argue that a constructivist analysis, in some form, is a conditio sine qua non for such a politics. Such an analysis stresses the malleability of technology, the possibility for choice, the basic insight *that things could have been otherwise.* But technology is not always malleable; it can also be obdurate, hard, and very fixed. The second step, then, is to analyze this obduracy of sociotechnical ensembles, to see what limits it sets to our politics. And finally, as a sort of postscript, I want to comment generally on the possible role of STS studies in the politics of technology.

The constructivist perspective provides a rationale for a politics of technology and it exemplifies the possibility of a social analysis of technology. Demonstrating interpretative flexibility makes it clear that the stabilization of artifacts is a social process and hence subject to choices, interests, and value judgments—in short, to politics. If one does not accept interpretative flexibility, one is almost certainly bound to fall prey to determinist thinking.[16] Few students of technology would take a purely determinist stand nowadays,[17] but the issue remains crucial for any discussion of the political relevance of technology studies.

Determinism inhibits the development of democratic controls on technology because it suggests that all interventions are futile. This is as true for science as it is for technology (Bijker, 1985; Collins and Pinch, 1993). If scientific facts are dictated by Nature, rather than constructed by humans, then any given scientific controversy (for example, about the risk of radiation) will necessarily be resolved only when it is shown that one party to the debate is "right" and the other "wrong." If we accept the idea that the debate is only about Nature, then it is quite reasonable for citizens to react by standing on the sidelines and saying "let the scientists sort that out among themselves." Likewise, if we do not foster constructivist views of sociotechnical development, stressing the possibilities and the constraints of change and choice in technology, a large part of the public is bound to turn their backs on the possibility of participatory decisionmaking, with the result that technology will really slip out of control.

Without an understanding of the interpretative flexibility of sociotechnical ensembles, the analysis of technology and society is bound to reproduce only the stabilized meanings of technical artifacts and will miss many opportunities for intervention. But interpretative flexibility needs to be demonstrated in a rigorous way that goes beyond the simple level of observation that "technology is human-made and therefore subject to many societal influences." The constructivist argument is that the core of technology, *that which constitutes its working,* is socially constructed. This is a way to take up the challenge of unpacking the politics of artifacts and thereby overcoming the standard view in which "blaming the hardware appears even more foolish than blaming the victims when it comes to judging conditions of public life" (Winner, 1986: 20).

Arguing for the malleability of technology does not imply that we can forget about the solidity and momentum of sociotechnical ensembles. Overly optimistic expectations based on a false sense of infinite malleability can easily cause disillusionment. A politics and a theory of sociotechnology have to meet similar requirements in this regard: a balance between malleability and obduracy in politics, and a balance between actor and structure perspectives in theory.

In my discussion of semiotics, I argued that the fixing of meanings that occurs during the formation of a technological frame is a form of power. I will now further specify this argument in terms of the obduracy of sociotechnical ensembles. Artifacts have been described in previous chapters, albeit implicitly, as bundles of meanings, as exemplars, and as boundary objects. The descriptive model started by emphasizing the meanings attributed by relevant social groups. These meanings were said to constitute the technical artifact. Does this imply that such "bundles of meanings" have unbounded flexibility? Can relevant social groups fantasize whatever they want, without constraints? Of course, they cannot. Attributions of meaning are social processes and, as such, are bound by constraints. Previous meaning attributions limit the flexibility of later ones, structures are built up, artifacts stabilize, and ensembles become more obdurate. The concept of "technological frame" made sense of this process. Ongoing interactions with an artifact, within and between relevant social groups, results in the creation of a technological frame that bounds the attributions of meanings by relevant social groups.

An important element of any technological frame is the *exemplary artifact*, and this is the second way in which artifacts have been described in this book. An artifact in the role of exemplar (that is, after closure, when it is part of a technological frame) has become obdurate. The relevant social groups have, in building up the technological frame, invested so much in the artifact that its meaning has become quite fixed—it cannot be changed easily, and it forms part of a hardened network of practices, theories, and social institutions. From this time on it may indeed happen that, naively spoken, an artifact "determines" social development. As a sociotechnical ensemble, it is at the same time the result of micropolitical interaction processes and one of the elements of a semiotic power structure.

To analyze the obduracy of sociotechnical ensembles, it is also helpful to look at artifacts and ensembles in their role as *boundary objects*.[18] Part of the closure and stabilization process is the creation of inside/outside boundaries.[19] The concept of "inclusion" is used to describe the boundary area between inside and outside: Actors with a high degree of inclusion are more to the inside than actors with a lower degree of inclusion.[20]

As an example, actors willing to participate in the fluorescent lighting market were required by General Electric and the utilities to accept the high-intensity lamp as the only daylight fluorescent lamp in the game. A certification scheme for lamp fixtures and other auxiliaries was designed to give the exemplary high-intensity lamp this meaning. Creating the certification scheme as an obligatory passage point helped to establish the specific form of semiotic power by which General Electric tried to hold the other lamp producers in bondage. The actual high-intensity lamp was an obdurate element in this semiotic structure, helping to create a boundary between the inside and the outside of the fluorescent lamp technological frame. For an actor outside the frame that was being built up around the high-intensity lamp, it became obligatory to produce (or sell, or buy) high-intensity lamps; actors who would not comply were not allowed inside.

Typically a closure process results in one relevant social group's meaning becoming dominant. A new technological frame is formed, shared by several social groups that until then could be represented by separate frames. The formation of the Bakelite frame through the enrollment of automotive engineers and radio amateurs is an example. Bakelite had an increasingly fixed meaning when it was used in the negotiations between employees of the General Bakelite Corporation and engineers of the automobile, radio, and chemical instrument manufacturing industries. The artifact Bakelite thus functioned at the same time as an element in Baekeland's micropolitics of power and as a boundary artifact in the emerging semiotic power structure of the new Bakelite technological frame. We might say that Bakelite was a form of currency, allowing the negotiation of new relationships between previously unrelated social groups. The boundary artifact Bakelite helped to link, in an almost physical sense, the different social groups into one new semiotic structure.

The obduracy of technology can take on at least two different forms, one associated with the artifact as exemplar, the other with the artifact as boundary object. Artifacts as "currency boundary objects" are, by definition, primarily used by actors with a relatively low inclusion, although highly included actors may also use them strategically. Artifacts as exemplars are typically used by actors with a high inclusion.

For engineers of the Bakelite Corporation, the molding material was an important element in the technological frame. Because it had a high inclusion in that frame, the molding plastic set their research and design agenda with high specificity. The meaning of the artifact, as it resulted from the stabilization process, was quite unambiguous for these actors. This is, however, not the same as saying that such a sociotechnical ensemble has one monolithic, undifferentiated meaning. For actors with high inclusion, the exemplary artifact is *unambiguous* and *constrains* action, but it is also highly *differentiated* and enables them to do many things.

Bakelite engineers knew how many variables had to be controlled to produce specific forms of the artifact, they knew how many different shades could be produced, and they knew how tricky the manufacturing process could be.[21] Thus this artifact was "hard" for these actors with high inclusion, but in the very specific sense of enabling and constraining interaction and thinking. It was not hard in the sense of having one fixed, monolithic meaning. For actors with low inclusion, the situation is quite different: The sociotechnical ensemble, as an element of a technological frame, does not guide their interactions and thinking very strictly, but it does have a relatively undifferentiated, monolithic meaning.

For actors with low inclusion, the artifact presents a "take it or leave it" decision. They cannot modify the artifact if they "take" it, but life can go on quite well if they "leave" it. For highly included actors, on the contrary, there is no life without the exemplary artifact, but there is a lot of life within it. The obduracy of artifacts as boundary objects for actors with low inclusion consists in this "take it or leave it" character. For such actors, there is no flexibility and there is no differentiated insight; there is only technology, determining life to some extent and allowing at best an "all or nothing" choice. This is the obduracy of technology that most people know best, and it is what gives rise to technological determinism.

There is an interesting similarity between this view and Donald MacKenzie's analysis of uncertainty. MacKenzie (1990) observes a high uncertainty about technology and science among two groups of actors—those with high inclusion (my term) and those with low inclusion. In between, he conjectures, a "certainty trough" may exist (figure 5.1). My analysis suggests that the "uncertainty" at the right-hand end of the curve is due to the obduracy of the sociotechnical ensembles in the "take it or leave it" sense, while at the left-hand end it is due to their high differentiation for highly included actors (figure 5.2). Describing the differentiation of uncertainty as occurring along a single dimension erroneously suggests that the two types of uncertainty are the same. Consequently, I would argue that MacKenzie's trough is not a good representation of what actually occurs. Artifacts can have different shades of obduracy for actors with different degrees of inclusion; but when the boundary of a technological frame is passed, the character of this obduracy changes fundamentally.

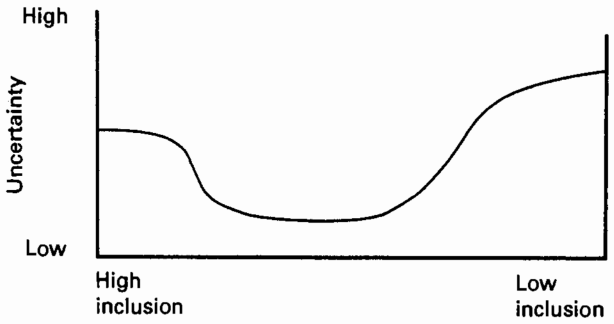

Figure 5.1
The "certainty trough" according to MacKenzie (1990: 372)

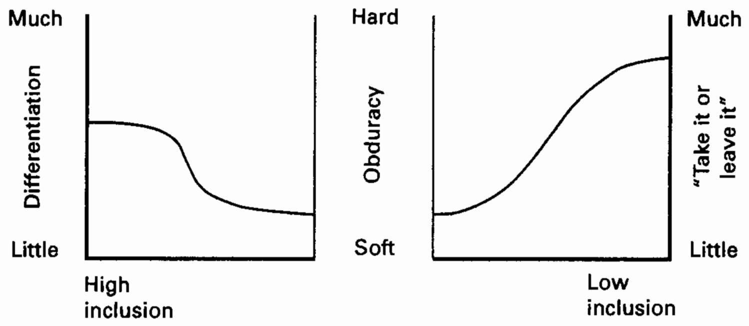

Figure 5.2
Two types of obduracy of technological ensembles, depending on the degree of inclusion

Artifacts as boundary objects, in the form of obligatory passage points or currency, result in obduracy because they link different social groups to form a (new) semiotic power structure. Making a "take it" choice with respect to such an artifact leads to inclusion in the corresponding structure. One then becomes involved with power relations to which one would otherwise—in the case of a "leave it" choice—be immune. If you buy a car, for example, you become included in the semiotic structure of automobiling: cars-roads-rules-traffic-jams-gas prices-taxes. This will result in your exerting power, for example by choosing to use the car during rush hour and thereby contributing to a traffic jam, but it will also subject you to the exertion of power by others in that same jam. If you choose not to own a car, jams and oil prices simply do not matter.[22]

Artifacts as exemplars result in obduracy because they constitute to an important degree the world in which one lives. This also implies inclusion in a semiotic power structure, but with different possibilities and effects. There are now many alternative power interactions that involve the exemplary artifact. Leaving the car standing is a less likely option, but changing driving hours or routes (to beat the traffic jams), changing from gasoline to diesel or liquid gas (to beat the taxes), and changing to a smaller car (to beat the parking problem) are all real possibilities.

In the constructivist perspective, then, sociotechnical ensembles manifest at least two types of obduracy. More precisely, this obduracy, to an important degree, constitutes the semiotics of power, and it is within this semiotic structure that the micropolitics of power are staged.

The micropolitics of power can focus on the deconstruction of the powerful, on softening the obduracy of the sociotechnical ensembles that constitute the semiotic power structure. The bicycle case provides an example. The sociotechnical ensemble of Macho Bicycle, Victorian morals, and "young men of means and nerve" was part of a semiotic power structure that prevented women from using the bicycle. One important factor in unmaking this oppression was a softening of the obduracy of the Macho Bicycle. As I have described, this happened largely through the actions of racers on low-wheeled "pneumatic" bicycles—racers who were probably not more interested in furthering the cause of women's emancipation than were their brethren on the high-wheeled Ordinaries. But once the high-wheeled machine had lost its obduracy, the semiotic power that had excluded women from bicycling lost its coherence and force. It became feasible to make other elements that would lead to new ensembles: low-wheeled bicycles, women's frames, bloomers, different morals.

A similar, though much shorter, process was the softening of the high-efficiency daylight fluorescent lamp. This lamp had almost everything it needed to become the starting point of a new technological frame, but its deconstruction during the load controversy prevented the process of building that frame. Bakelite was also subjected to deconstruction processes, though without much effect. The most conscious deconstruction strategy was Lebach's, who tried to argue that Baekeland's patents were secondary to his own. Another example of the micropolitics of power, though less consciously strategic, was the negative image that plastics acquired during World War I. This could have resulted in a softening of Bakelite as an exemplary artifact, and it underlines the importance of having a conception of power that is not exclusively associated with the strategic actions of specific actors. Consumer behavior and product image may, under certain circumstances, turn out to be more important elements in the micropolitics of power than patent agreements, smoothly running production plants, or economic ownership relations.

Other micropolitics can result in a softening of the obduracy of boundary artifacts. In this case, it will be a matter of influencing the take-it-or-leave-it choice of actors with low inclusion. Ridiculing bicyclists and setting restrictive rules for bicycling in towns were micropolitical ways of discouraging people from cycling, but they left the bicycle as an exemplary artifact untouched. Nevertheless, if this strategy had been successful, the whole sociotechnical ensemble would have been deconstructed and the associated semiotic power would have crumbled. (This is exactly what had happened some decades earlier with the hobbyhorse craze.)

The refusal of some utilities to inform the public about the fluorescent lamp is another example of deconstructive micropolitics focused on an artifact as boundary object. Executives like Bremicker were not successful in tampering with the new lamp in its exemplary role, but their unwillingness to show it in their display rooms and to include it in their marketing campaigns posed a serious threat that might have softened the artifact as boundary object to such a degree that Bremicker's Northern States Power Co. could have "escaped" the semiotic power in which it was increasingly encapsulated by the Mazda companies.

Micropolitics can also lead to a bolstering of sociotechnical ensembles. Let me start with the contemporary example of routine ultrasound scanning.[23] Giving all pregnant women an ultrasound scan would effectively make the scan into a boundary device drawing women into the semiotic power structure of medical hospital technology. In the Netherlands, where a considerable number of women give birth at home, this process has not reached closure, and women can still choose *not* to have such a scan. "Not taking" this artifact would be a strategy for weakening medical power, while making women accept the artifact as "producing a nice picture," or as "a safe precaution," or as "a standard procedure" would result in the further extension of medical power, using the obduracy of the scan as boundary artifact.

Several of the processes that I identified in the discussion of the configuration model are also examples of micropolitics resulting in an increasing obduracy of artifacts. Enrolling the automobile and radio engineers into the Bakelite frame, negotiating a cost comparison method with the utilities, and selling a tricycle to the Queen all led to a bolstering of sociotechnical ensembles and their associated semiotic power structures.

Although some of the these examples do involve conscious strategies by particular actors, there is more to the politics of technology than explicitly planned, rationally decided, conscious action. This has been one of my reasons for introducing the structural semiotic aspect of power in the first place, and for emphasizing the need for balance between actor- and structure-oriented perspectives generally.[24] Technology is socially shaped and society is technically shaped, but there need not always be explicit "causal" links between specific artifacts and relevant social groups. The combinations of technological frames with actors and artifacts, and of the semiotics of power with the micropolitics of power, are meant to describe this process of developing sociotechnical ensembles.

Postscript: The Paradox of Sociotechnical Politics

This book started at the level of single artifacts and their social shaping and then moved to level of relevant social groups that are constrained and shaped by technology. Now, at the end, we have arrived at the highest level of aggregation—technological culture.[25] At this level the STS problematic with which I started can be given new formulations. Many of these have already been discussed: a constructivist view of artifacts and facts, the integration of the technical and the social into a new unit of analysis, a conception of power that combines structural and actor-oriented aspects, and finally an analysis of the hardness of technology. There is one final, general implication with which I would like to conclude, but I have chosen to do this by way of a postscript since it is more a suggestion for a research agenda than a well-polished conclusion.

One of the major implications of the analysis so far is that there are no actors or social groups that have special status. All relevant social groups contribute to the social construction of technology; all relevant artifacts contribute to the construction of social relations. This is mirrored in the power conception I have outlined. Both the semiotic and the micropolitical aspect of this conception stress that sociotechnical change cannot be understood as the product of one prominent actor, whether an inventor, a product champion, a firm, or a governmental body. The consequences of this are quite radical. Technology assessment methods, which are given a priority role by legislatures, and innovation management theories, which are given a similar role by firms, are equally inadequate. And even *my* attempts to describe micropolitical strategies to change technology and society will never yield a conceptual framework or suggest a set of policy instruments that are certain to guide sociotechnical change in a particular direction. This is a matter not of postmodern relativism but of recognizing that there will always be other actors who contribute to the construction of society and technology, actors that cannot be controlled.

One consequence of this observation is that we can no longer imagine that constructivist STS studies will principally or primarily benefit any specific social group, such as the less privileged or less powerful. One might attempt to argue that the sorts of STS studies I have discussed, by highlighting the constructed nature of facts, artifacts, social orders, and sociotechnical ensembles, will allow those who are kept hostage by the semiotic power structures involved—nonscientist citizens, consumers, patients, women, workers, neighbors to a chemical or nuclear plant, environmentalists—to sever these bonds and free themselves.[26] Although this may happen, there is no guarantee that it will always work out this way. First, science and technology may also be fruitfully employed by the less privileged. Environmentalists, for example, frequently use scientific data to argue their case, and the last thing they would want is to see those findings and arguments deconstructed.[27] And second, there is no reason why the powerful may not draw on the insights of the STS community or even hire constructivists to strengthen their micropolitical strategies. The relativizing force of constructivist STS studies thus prevents it from attaining a neat and simple political correctness.

STS work should not stop here. The observation that all citizens have access to insight might lead some to argue for a decentralization of control and responsibility—"local democracy," for example, in place of a national regulatory system. Such "free-market regulation" would leave larger semiotic power structures uncritically in place. The question of how a politics of technology can help establish institutional and structural ways of guaranteeing the democratic nature of technological culture thus reappears on the agenda. Its solution, however, necessarily takes the form of a paradox, recognizing that no principally prioritized group can exist in society—there is no Leviathan—while at the same time proposing some form of institutional regulatory system.

This open, and potentially paradoxical, agenda for future research mirrors the thrust of this book. Although I have wanted to argue for a politics of technology (rather than, for example, technology policy), and although I have tried to develop a constructivist theory of sociotechnical change (rather than, for example, an economic one), I have also wanted to tell my three stories with due respect to their own richness. Consequently, I have tried not to make this book into a closed world, which would leave no room for alternative interpretations of the stories. This, then, is my bottom line: a plea for combining empirical work with theoretical reflection to strengthen the links between academic STS studies and politically relevant action—a main route for STS studies out of what started as an academic detour.

"The time has come," the Walrus said,
"To talk of many things:
Of bikes—and bakelites— and bulbs—
Of theories—and kings . . ."[28]

Notes

Chapter 1

1. I will use the term "artifact" to encompass all products of technology: it denotes machines as well as technical processes, hardware as well as software. Thus artifacts include the bicycle, the chemical reaction patented by Baekeland, a complete lighting installation, the starter switch inside a fluorescent lamp auxiliary, and a method for cost comparison between incandescent and fluorescent lamps.

2. See Cutcliffe (1989) for a description of the emergence of American STS programs. Jasanoff et al. (199~~4~~) represent the state of the art in academic STS studies. The situation in the Netherlands is different from many other countries in that science and technology studies are the offspring of a marriage between two groups in particular: politically motivated STS academics and philosophers of science. Sociologists and historians did not play an important role in the early days of Dutch science studies. See Bijker (1988) for a review of the roots of Dutch science and technology studies. <

3. See Bijker, Hughes, and Pinch (1987a) and Bijker and Law (1992a) for descriptions of this research program and for examples of empirical and theoretical work within it. See Bijker (199~~4~~) for a general review of sociohistorical technology studies.
5

4. Blume (1992) contributes to bridging the gap between economic studies of technical change and sociological work in the constructivist tradition. Winner (1991) argues for the need to complement recent empirical work in the constructivist tradition with philosophical and political analyses of technology.

5. Manuals describing resinous materials do mention Bakelite, but not with the amount of attention that, in retrospect, we would think justified. Professor Max Bottler (1924), for example, devoted only one page to Bakelite in his 228-page book on resins and the resin industry.

6. See Staudenmaier (1990) for a comprehensive review of the current state of the history of technology. Staudenmaier's monograph (1985) analyzes twenty