In search of insights into the generation of techno-economic trends: Micro- and macro-constituencies in the microprocessor industry *

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In the field of technology policy, few challenges are more intriguing than understanding the nature of technical and market trends. This paper deals with this problem by using the sociotechnical constituencies approach in order to integrate the treatment of "micro"/"macro" issues – from product to industry. The case study is that of the microprocessor industry where at present a Risc (reduced instruction set computer) technology is emerging in a field where a powerful and far-from-exhausted Cisc (complex instruction set computer) technology tends to occupy almost every segment of the market. The analysis reveals how emerging product-constituencies do implement pro-active trend-creating strategies in order to establish themselves as industrial trends, and, by so doing, they simultaneously re-define the existing content of the "macro" industrial level. The study also reveals the important role of the nature and maturity of microprocessor technology in conditioning the constituency-building strategies implemented by different players. Microprocessor technology is specifically characterised as an architectural, codified-knowledge component with indirect network externalities and weak appropriability regime. Finally, the paper also highlights the potential risks of both fragmentation and complete proprietary control of technology in technological processes involving strongly competitive situations.

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1. Introduction

In the field of technology policy, few challenges are more intriguing than understanding the nature of technical and market trends. Closely related to the formation of *de facto* standards, technical and market trends refer to those solutions or processes (e.g. hardware and software approaches and devices, products, processes and their dynamism – speed of product-cycles, and the like) which become widely accepted within technical communities, as well as within industry and the market. Once established, trends play an influential part in setting and reproducing the course of technical, industrial and market events. Indeed, to an important extent they become, or are, the *expected* course of events – a perception which seems to rebound on the players generating an implicit element of self-fulfilment.

1.1. Trends and trajectories

The nature and development of technological trends have not received much direct attention. Approaches directly tackling the problem seem to be lacking. Perhaps one of the closest is the theme of "technological trajectories", insofar as technological trends can be seen as creating and eventually "imposing" a trajectory on the course of development of a given industry. The seminal work in this perspective comes from economists – particularly, from the school of evolutionary economists which includes scholars such as Dosi

[19], Rosenberg [58] and Nelson and Winter [51]. These authors have introduced such concepts as "natural trajectories", "selection environment", "technological regimes", and "technological paradigms". Basically, this set of concepts permits them to portray the development of technology in the following manner. Within a technological realm, which would involve knowledge, know-how, procedures, experience, and physical devices and equipment, it is possible to distinguish what Dosi [19] calls "technological paradigms". A technological paradigm, which is a more elaborated version of Nelson and Winter's "technological regime" [51], is a "model" and a "pattern" of solution of *selected* technological problems, based on *selected* principles derived from natural sciences and on *selected* material technologies. [1] Consequently, such a paradigm determines the field of enquiry, the procedures and the tasks to be accomplished by technologists. It does so by focusing their imagination within the confines of the paradigm, and on to problems implicit in the fulfilment of the paradigm's potential. This means that, once established, a technological paradigm becomes in itself a strong determinant of the direction of technical change.

The establishment of a given paradigm is a matter of selection by economic forces, together with institutional and social factors which may involve, for instance, the role of public agencies, the military, and so on. These factors constitute what Dosi [19] calls "the selective device", and Nelson and Winter [51] call "the selection environment". This selective device establishes the development of one paradigm over that of other possible paradigms and, later (primarily through the market) it also selects among internal paradigmatic developments by awarding or denying the possibility of commercial success to different paradigm-based products. A key element is that, once established, a technological paradigm shows a momentum of its own: this contributes to defining the "normal" problem-solving activity of technologists operating within the paradigm. This momentum of problem-solving activity constitutes the "natural trajectories" of Nelson and Winter [51], and Dosi's "technological trajectories", and has also been identified by Rosenberg [58], through such concepts as "the compulsive sequence of technical change" emerging from imbalances and disequilibria in the evolution of technical systems. In brief, within this perspective, the development and diffusion of technology would proceed, first, via the establishment of technological paradigms (which is itself a process of selection by the economic, institutional environment); and second, once paradigms become established, by the process acquiring a momentum of its own, following natural trajectories implicit in the technical potential of the paradigms. Of course, the scale of this process will vary from technology to technology, but it is not difficult to see that, if a paradigm becomes widely accepted (say within an industry), then there is a great deal of resemblance between the momentum of the paradigm and the development of an industrial trend.

In this paper, the intention is to probe deeper into the nature of the processes whereby trends become established. One possibility is to look more closely at the workings of the "selective device" or "selection environment". Although this option has a certain appeal, it is in fact limited by the lack of systematic treatment of these concepts. In addition, the idea of "selection environment" itself implies an emphasis on exogenous factors in the establishment of trends when, as we shall see below, the process seems to be not just one of profound interaction between exogenous and endogenous factors, but also one in which exogenous and endogenous factors actually transform into each other, depending on the level of analysis. In this respect, the understanding of trends would touch on one of the major theoretical issues in the field of technology and society (T&S) – namely, the relationships between "micro"- and "macro"-levels of analysis.

1.2. Trends and the problem of the "micro" and the "macro"

The establishment of a trend is basically a matter of transforming a technical solution (a product or a process) into a widely accepted phenomenon – a force to be reckoned with, which shapes the designs and actions of players in a particular field. As indicated, any explanation of

[1] Dosi's concept of technological paradigm represents an attempt to transfer into the field of technology T. Kuhn's concept of scientific paradigm, used in his conceptualization of scientific revolutions. See Kuhn [40].

this process must touch on the major theoretical issue of the relationships between micro- and macro-levels of analysis. By "micro" I roughly understand that level of analysis which concentrates primarily on the development of particular products or processes, without much concern, for instance, for the broad industrial or market realities to which they belong. [2] In contrast, "macro" would include those approaches whose central preoccupation is to deal with, for instance, broad patterns of technological developments in society, or the development of industries where a product is related to many others. Relationships between "micro" and "macro" approaches in the understanding of technology have not been easy to define. However, it seems to me that there are at least three ways in which it is possible to talk of "micro"/"macro" relationships in the present literature on technology and society:

(a) *The vertical upward approach, or accessing the "macro" to serve the "micro".* This would come from the "micro" school concentrating primarily on the actors and processes directly shaping the development of a given technology. This approach would recognise the relevance of political and other events which, although not directly related to the development of the specific technology, may have an impact in the course of its development. The incorporation of such broader issues in the analysis may be seen as accessing a "macro" level impinging on the technological process. Examples of this may be found in the work of Law [44] on the TSR2 combat plane, Callon [8] on the electric vehicle, Hughes [33] on the electrification networks, and MacKenzie [46] on missile guidance systems.

(b) *The horizontal diffusion approach, or building from the "micro" to the "macro".* This starts from the "micro" level, and tries to explain the mechanisms for the widespread acceptance of a technology by society. Sociologists, in particular, have developed concepts such as "closure" and "obligatory point of passage" to try to describe some of these mechanisms. [3] In turn, economists trying to model the process whereby a technology becomes a standard have talked of "sponsorship", "bandwagon" and "lock-in".[4] In addition, much of the work done on the theme of diffusion of technology, from many different perspectives, would tend to fit this horizontal category of "micro"/"macro" analysis. The work of the historian Thomas Hughes [32,33] and of the economic historian Nathan Rosenberg [58,59] is particularly relevant – as indeed is a great deal of the literature on the causes of product successes and failures [36,45,47,54,56].

(c) *Vertical downwards approach, or accessing the "micro" to serve the "macro".* This starts from a "macro"-level of analysis, assuming a societal structure basically driven by a complex of dominant social, economic and political forces which broadly shape the course and dynamic of technological development. This perspective tends to access micro-level technological processes to substantiate, or display them in a manner which is consistent with, the analysis of broad societal patterns [18,37,52,64].

These three approaches indicate progress in the treatment of "micro"/"macro" relations. Of particular relevance to the problem of trends, they provide certain elements to explore, for instance, what is behind the establishment of key patterns of development of industries and technological capabilities. But more is needed. As with

[2] To date, the "micro" approach has been prominently related to the sociology and history of technology – as, for instance, in the approach known as the Social Construction of Technology (SCOT) school. A reader concentrating some of the most important work of the SCOT school is Bijker et al. [2].

[3] "Closure" relates to the process whereby certain technologies eventually prevail over other alternatives [57]; whereas "obligatory point of passage" relates to the process whereby technologists and institutions succeed in making their products almost a necessity for many people [42,43]. Sociologists have also emphasised the importance of the "horizontal diffusion" approach in analysing the evolution and transformation of power relations in society at large. See Latour [41,42].

[4] "Sponsorship" relates to a supplier trying to establish a technology through below-cost pricing (i.e. strategic penetration pricing) at the beginning of the technology's life. "Bandwagon" relates to the promotion of a technology with a view to building up an early installed base of physical capital (previously sold equipment), and human capital (trained users). "Lock-in" relates to the process whereby users or adopters of a technology cannot or will not easily change to another competing technology. The corollary is that a competitor technology is "locked-out" from a given market. Monopoly would be lock-in to a single technology. See Farrel and Saloner [25], David [17], Katz and Shapiro [38,39] and Arthur [1].

"trajectories", the difficulty lies in the present lack of any systematic conceptualisation helping us not just to establish links between "micro"- and "macro"-levels of analysis but, indeed, to integrate them. Yet the understanding of trends seems to require precisely this kind of analytical integration. The critical question then is: could there be ways of developing conceptual tools which enable the integration of, and movement between, "micro"- and "macro"-levels of analysis?

One of the aims of this paper is to suggest one possible way, although very much in a tentative fashion, and with no intention of making sweeping claims. The idea is to explore the potential of the "sociotechnical constituencies" approach, which I have already used to deal with issues at both "micro"-level and "macro"-level of

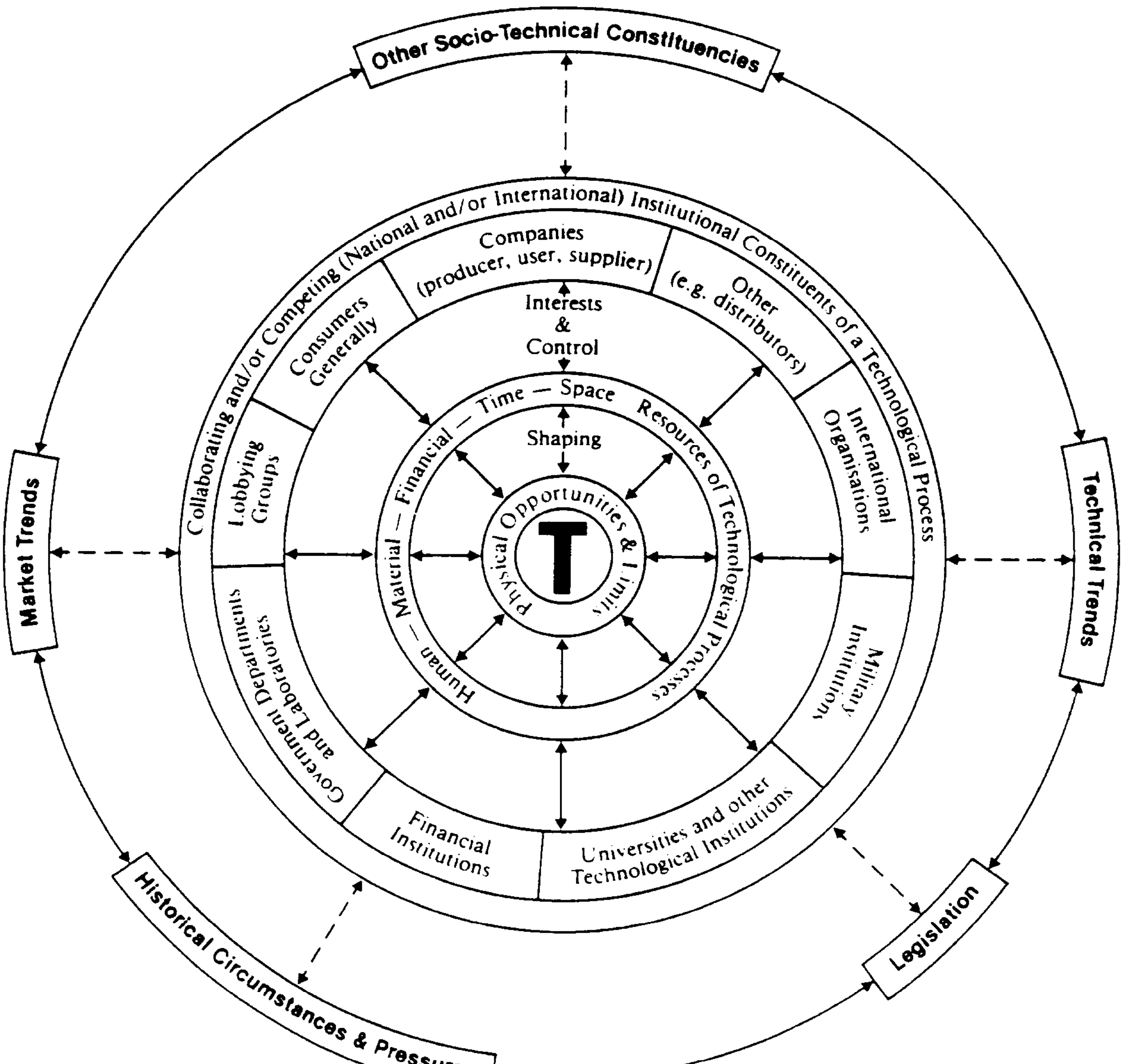

Fig. 1. Institutional representation of a possible socio-technical constituency.

analysis. [5] In particular, I want to explore its potential in relation to the issue of *industrial* trends. This means that society-wide trends related to the "vertical-downward approach" will be beyond the scope of this paper. Two steps are proposed. First, the definition of conceptual links in the "constituencies" approach, which allow for the analysis of a "micro"-constituency to be integrated to that of ever broader constituencies to reach the level of industry. Secondly, the implementation of this approach to a particular case-study of formation of trends in a given industry. The chosen industry is that of microprocessors where, at present, a major battle is taking place between an emerging and a long-established computing architecture. Specifically, the emerging Risc (reduced instruction set computer) architecture is striving to become firmly established as the upcoming trend, whereas the long-established Cisc (complex instruction set computer) architecture is striving to show that the trend is in fact for Cisc to remain dominant.

With this purpose, the paper is divided into several sections. First, a brief section on the sociotechnical constituencies approach, which is here further developed to deal with the problem of trends. Then sections 3 and 4 are devoted to the implementation of the approach. Specifically, section 3 provides a techno-economic and "constituencies" characterization of the microprocessor industry. This section also reviews advances and trends in semiconductor technology and systems markets, insofar as they directly concern the development of the microprocessor industry. Section 4 looks in detail at the development of the broad Risc and Cisc constituencies, focusing particularly on the strategies of their leading micro-constituencies. Section 5 concludes with some thoughts on the "micro"/"macro" issue, the constituencies approach, and the understanding of trends in the microprocessor industry.

2. Sociotechnical constituencies

The sociotechnical constituencies approach starts from the premise that the generation of technological capabilities is a complex process in which technical and economic factors and trends interact with individual and institutional actors' expertise, visions, interests and cultural dispositions in a context of evolving market and political pressures [49]. Its aim is to provide an environment for an "eclectic multi-disciplinary" treatment of technology, by facilitating the integration of selected insights from selected disciplines in order to provide a coherent account of the various issues and factors involved. As illustrated in fig. 1, the "constituencies" approach puts the technological process at the centre of the analysis, and the meaning of technology (T) is not confined to a single specific product or process. Indeed, in this case the concern is with a range of microprocessors, the broad architectures that group them, and the microprocessor industry at large.

Sociotechnical constituencies may be defined as dynamic ensembles of technical constituents (tools, machines, etc.) and social constituents (people and their values, interest groups, etc.), which interact and shape each other in the course of the creation, production and diffusion of specific technologies. Thus, the term "sociotechnical constituencies" emphasises the idea of interrelation and interaction in technological development. It makes possible to think of technical constituents and social constituents but always stressing the point that in the technological process both kinds of constituents merge into each other. This differentiates "constituencies" from the term "communities" which normally refers to people only. Sociotechnical constituencies are never static, they are always evolving and changing their mix in ways which are reflected in growth or decline. A manifestation of this change may be seen, for instance, in the evolution of market shares of a constituency's products. But this is only one possible manifestation, because some constituencies may not be geared to the market at all, or simply fail to reach it. Thus, although a market share always implies the existence of a constituency, the opposite is not necessarily true.

Within constituencies institutional interaction may be competitive, collaborative or a combination of both. In addition, this interaction may involve institutions of the same type (e.g. a number of companies) or institutions of different types (e.g. companies, universities, government). It may take place at a national or international level.

[5] See Molina [48] for a "macro" approach and Molina [49,50] for "micro" approach of the vertical upward and horizontal cases.

Mechanisms of collaboration may include business alliances or second-source agreements, but there might be constituencies with no such arrangements. The balance between collaborative or competitive interaction will fundamentally affect the evolution and dynamism of the resulting sociotechnical constituency. For example, competitive interaction between companies may stimulate technological dynamism by injecting a sense of urgency and threat. It may simultaneously lead to fragmentation of resources – and discourage constituents from addressing problems (often long-term) which are perceived as being beyond the resources of each individual constituent.

Collaboration may counteract this harmful fragmentation of resources, but it demands a careful approach; each institution is likely to have different interests, imperatives and expectations, dictated by its history, its current activities, and possibly by its ethical stance as well as by idiosyncratic practices. It is possible to regard institutional interaction as the interaction of a number of micro-cultures.

In this analysis, the extent to which any given technology is diffused is conditional upon the relative success or failure of the sociotechnical constituency creating and promoting it. The success or failure of the sociotechnical constituency in turn depends largely on the ability of the constituents to strike a balance between their individual interests and the development of the constituency as a whole.

Sociotechnical constituencies have certain essential features, which are highlighted in the example of fig. 1: [6]

(1) The double-ended arrows indicate that influence may be bi-directional: from the inner circle of technology (T) towards the outer circles and vice versa, in a single fluid process.

(2) Moving outwards from the first, central circle (T), the second circle indicates that technology is conditioned by the opportunities and constraints imposed by the physical world and its own nature and state of the art at any given time. In other words, technology can only be shaped within the realm of the shapeable.

(3) The third circle indicates that technologies generally result from the integration of time and space, and human, material and financial resources. These resources are not static quantities, but change continuously as the sociotechnical constituency evolves. A single new idea generated by an individual implies a change in the constituency.

(4) The fourth circle shows that this integration of resources is effected through the interaction of institutions. Since these social constituents control the resources (directly or indirectly), they are able to influence the manner in which the resources are integrated. This allows them to shape the development of a given technology in accordance with their own interests, and generally in accordance with their relative weight within the constituency.

Thus, institutional constituents with control of resources make those resources available to further the development of a given technology because the development of that technology is perceived as furthering their own interests, as well as the various interests of collaborating constituents.

Despite their perception of benefit, institutions participating in a sociotechnical constituency do not invariably have a clear idea of where their specific interests lie in relation to a given technology. Nor does the development of this technology invariably follow the intended path or yield the results expected by the constituents. Often, unpredictable and possibly unidentifiable factors have unintended consequences which make the difference between success and failure. This uncertainty is inherent in the technological process, particularly where constituents are trying to break completely new technological ground.

2.1. Constituencies and the "micro"/"macro"

Figure 1 is again a useful start since, as we move to the outermost circle, it highlights the fact that the development of a given technology is not simply the result of an insular, intra-constituency process. It is also the result of that sociotechnical constituency's interaction with other sociotechnical constituencies, within its particular historical setting. It is influenced, for example, by legisla-

[6] It is worth stressing that not all sociotechnical constituencies will have the same mix of institutional constituents as the one exemplified in the diagram. For instance, some of them may be just national, some may not have any military constituent at all, etc. The variety can be infinite.

tive, technical and market trends which are themselves the result of interaction between sociotechnical constituencies (i.e. an inter-constituency process). Thus, technical and market trends are not really exogenous to constituencies: sociotechnical constituencies themselves create and alter them according to the extent of their relative strengths, dynamism and growth. On the other hand, it is true that once these trends gather momentum, they are likely to appear to many social constituents as an external force, a technology-shaping environment influencing the products of the constituency. This impression may be particularly strong where, for instance, companies are trying to establish new products in markets already occupied by strong competing constituencies.

Figure 2 (outer circle) takes this inter-constituency dimension further. It highlights the fact that this dimension is not just confined to, say, one product-constituency and its immediate competing and/or interacting constituencies. This

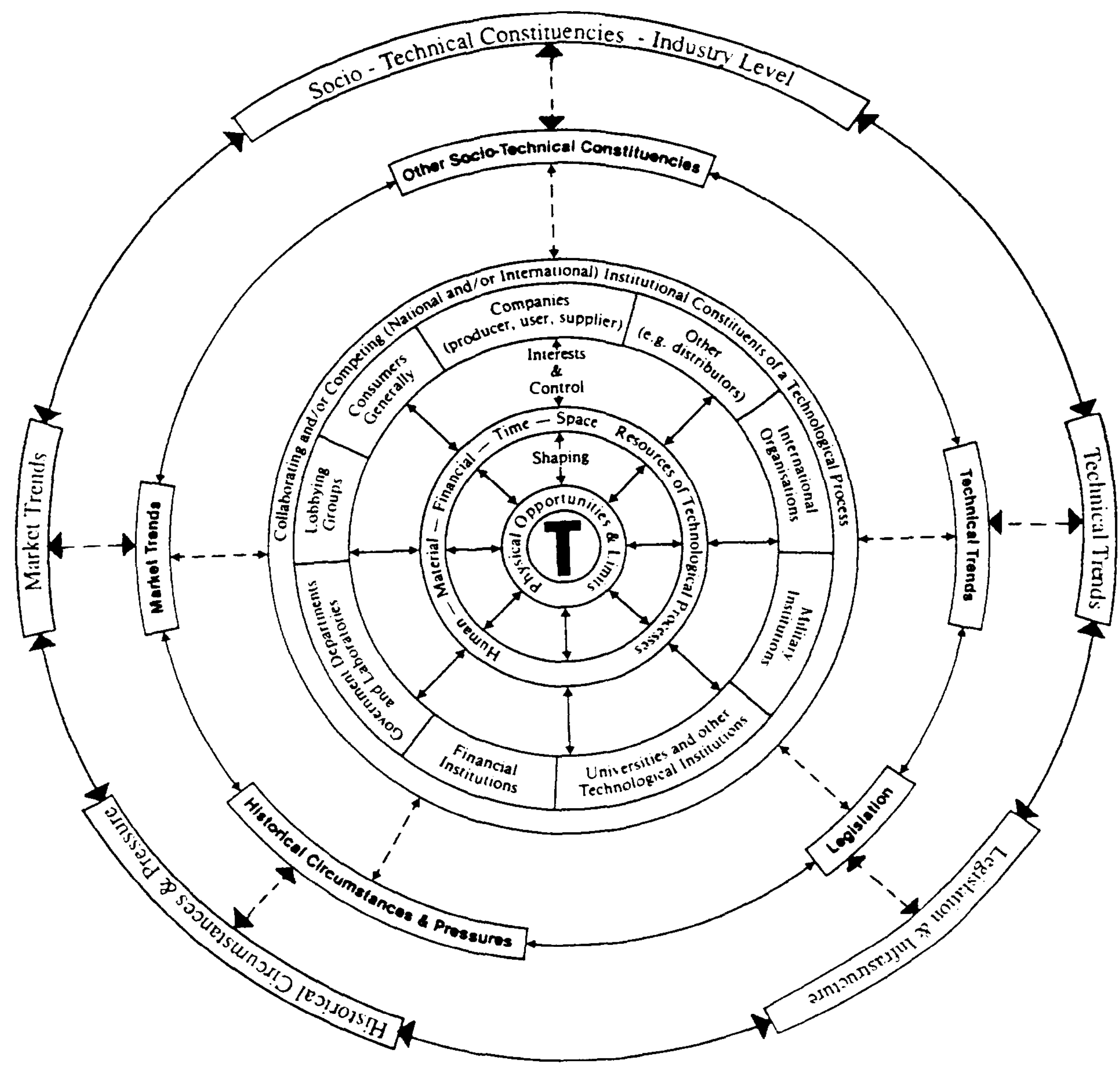

Fig. 2. "Micro"/"macro" representation of sociotechnical constituencies – industry level.

group itself may be subsumed into a broader constituency which, in turn, will be competing/interacting with other broader constituencies. In principle, this means that the inter-constituency dimension can be seen as expanding right out onto ever more aggregate levels, eventually reaching "macro" industry-wide dimensions. This analytical differentiation is useful, because different studies of technology may have different analytical levels of entry into an industrial sector. By helping to systematise the integral relation from the "micro" (e.g. product-constituency) to the "macro" (e.g. industry-constituency), it becomes possible not just to situate each of these studies into their overall context but, also, to relate them to one another.

A change of analytical level of entry in the aggregate "macro" direction, however, implies consideration of at least three new aspects.

First is that every higher aggregate level would always contain or subsume all previous levels. This means that specific product-centred constituencies would become sub-constituencies of broader levels and so forth. Or put in other words, competing and/or interacting constituencies at one level simply become constituents at another broader level of analysis. The result is that what was part of a product-constituency's environment now becomes an intrinsic part of the broader constituency.

Second, the aggregate constituencies have a reality of their own in that there will be clearly defined common aspects which will identify the sub-constituencies as members of a broader constituency. For instance, in the area of computers, different product-constituencies based on individual computers are normally classified together into broader architectural categories such as sequential (Von Neumann) computers and parallel computers. These broader categories provide the linchpin for aggregate but clearly identifiable constituencies such as the parallel computing constituency and the sequential computing constituency. In turn, these aggregate constituencies interact with each other within the even broader category of the computer industry in ways that underpin ever broader technical, market and legislative trends.

Third, as the analysis move from "micro" to "macro" and constituencies become constituents, there will be changes in the nature and driving factors of the broader constituency under analysis. New mixes of, and relations between, social and technical constituents will characterise each new more aggregate level of analysis. For instance, organisations such as trade associations may acquire much more prominence as mechanisms for "macro" constituency-building and, indeed, expressions of the reality of the "macro" constituencies themselves.

For the "constituencies" approach, the key implication of this "micro"/"macro" systematisation is that the basic tools for a constituency analysis entering at a "micro"-level are basically the same as the entry-level of analysis move towards increasingly "macro"-levels and vice versa. The key factor never to loose sight of, however, is that, whatever the entry-level, the "micro" and the "macro" are not separate: they belong to a single reality. In an industry, for instance, there can be no "macro" industrial level without "micro" product-constituencies. Although, at an extreme, if one single product-constituency were to dominate an industry, then there would be an identity between the "micro" and the "macro": the product-constituency would be the industry. This is a situation likely to be found during the early period of monopolistic advantages of a new technology which gives birth to an industry, I think this case of "micro"/"macro" identity has some useful implications for the understanding of the nature of trends. It can be posited as the ideal north towards which all product-constituencies seeking to become industrial/market trends (or standards) tend to develop. The reason is that the larger the proportion of an industrial sector which is accounted for by a single product-constituency, the stronger the chances that this product-constituency will shape the course of development (i.e. trends) of such an industry. Ultimately, this amounts to a product-constituency actually creating the "macro", in order to enhance its influence on the reality surrounding its development.

Before, it was said that technical and market trends are the result of interaction between sociotechnical constituencies. Now it is possible to suggest that, in fact, the establishment of such trends is an implicit goal in every constituency's pursuit of industrial success. In other words, this success would consist, precisely, in the effective transformation of a constituency's product into an established and well-recognised industrial force: a force that becomes a technology-shaping environment for everybody in the pertinent field, including the members of the originator-constituency themselves. This last point is critical because, as several product-constituencies interact to create the "macro" world of an industry, they are, at the same time, giving this industrial dimension a specific content and dynamism, which, in turn, reverses its influence on the "micro" level by shaping the limits and opportunities for successful constituency-building. This is the reason why, once industrial trends gather momentum, they are likely to appear as an external force influencing the development of all product-constituencies. The following sections will examine how this "micro"/"macro" problem is manifesting itself in the case of the microprocessor industry.

3. A techno-economic and "constituencies" characterisation of the microprocessor industry

There are few microelectronic technologies which hold such a strong appeal as microprocessors do. They are the building blocks of information processing and process control and symbolize the "intelligence" capabilities of information and communications technologies (ICTs). In microprocessors, the US semiconductor industry reigns supreme. The credit for the fundamental invention of the microprocessor belongs to the US semiconductor industry and so it still does today its world market leadership. In particular, two US semiconductor companies are at the forefront of this process. They are Intel and Motorola who between them have more than 90 percent of the market for the most advanced microprocessors.

Market / Architecture	EMBEDDED CONTROLLERS	GENERAL-PURPOSE MICROPROCESSORS	
		PCs & Low Cost Workstations	High-performance Work stations & Computers
CISC (complex instruction set computer)	*Motorola 68010/20/332* *Intel 80176/376* *NEC V-series*	*Intel 80286/386* *Motorola 68020/30*	
RISC (reduced instruction set computers)	*Inmos Transputer* *Acorn ARM (VL86C10/20)* *AMD 29000* *Integraph Clipper* *Intel i960* *National 3200 (re-targeted from workstations)*	*Acorn/VLSI ARM*	*Sun SPARC* *MIPS R2/3/4000* *Intel i860/i860 XP* *Motorola 88000* *Inmos T800/T9000*
CRISP (complex/reduced instruction set computer)	*Tron (Japan)*		*Intel 80486* *Motorola 68040* *Tron (Japan)* *Hyperstone (Germany)*

Fig. 3. Market and architectural segmentation of the microprocessor and microcontroller market.

When Intel created the first microprocessor two decades ago, the space was empty. It was a case of "micro"/"macro" identity. Intel created the industry and with it all the initial trends. Today any new microprocessor constituency would emerge into a world populated by many other constituencies. At one level some of these constituencies are direct competitors, at another level they are members of the same broader constituency, sharing common goals and competing against other broader constituencies for a stake in the global microprocessor arena. In this section, I briefly describe the main current tenets of this broader microprocessor world and the main micro- and macro-constituencies which populate it. This is done by focusing on the commercial arena, i.e. on the main microprocessor-families and broader architectural categories (e.g. Cisc and Risc) at present leading the market. This description is supplemented by a brief overview of related trends which are clearly influencing, or interacting with, the evolution of the Cisc and Risc constituencies. I treat these related trends as part of the industrial macro-constituency, to the extent that they have become established common features characterising the pattern of development of the entire industry.

3.1. Market and architectural segmentations

The two most common ways of broadly characterising the commercial microprocessor arena are by dominant architectures and by market segments. Figure 3 brings these two axes together and illustrates the names of some of the main players in each intersection. It must be taken into account that some of these microchips are manufactured under license by a variety of companies. Thus several other semiconductor companies are manufacturing microprocessors. [7] The figure refers only to the originator of the chips.

In terms of market segments, fig. 3 shows that microprocessors may be classified into two main types: embedded controllers or microcontrollers and general-purpose microprocessors (GP-microprocessors). In turn, general-purpose chips may be sub-divided into components for PCs (personal computers) and Low-End Workstations and components for High-Performance Workstations and Computers.

Embedded controllers are "hidden" preprogrammed processors providing computational power for control tasks in the widest range of automatic systems. These include from automatic coffee makers and laser printers to very sophisticated telecommunications networks. On the other hand, GP microprocessors are *reprogrammable* processors providing the compute engine for a vast array of products from personal computers and engineering workstations to supercomputers.

In terms of their architectures, fig. 3 shows that microprocessors may be classified into three main types: complex instruction set computer (Cisc), reduced instruction set computer (Risc) and a hybrid type referred to as complex/reduced instruction set computer (Crisp) [21]. Risc and Crisp microprocessors are fairly recent dating from the early and late 1980s respectively. On the other hand, the first microprocessors to be produced by the early 1970s were of the Cisc kind. The roots of Cisc microprocessors go back to the central processing units (CPU) of the early computers of the 1950s. Then, there was at least one important reason favouring the Cisc choice, namely, the high cost of internal memory which prompted designers to put as many computer instructions as possible into the central processing hardware [3].

In contrast, the Risc concept tries to reduce to a minimum the number of built-in instructions, leaving only the most frequently used. The instruction set of the processors is optimised around that reduced set of common instructions and more complex instructions are met by combining the instructions available in this reduced set. The idea is that the simplification of the instruction set will enable processors to work extremely fast. Risc chips emerged only during the 1980s, particularly, with the advent of 32-bit microprocessing technology which has enabled Risc to realise its potential for high performance [26].

Finally, the Crisp approach is more the result of the growing success and diffusion of Risc microprocessors. It is the answer of Cisc manufac-

[7] For example, Fujitsu Microelectronics manufactures the Sparc-based processor Sparclite, Philips also manufactures a Sparc-based processor. LSI Logic manufactures the LR33000 and IDT manufactures the R3051/2, all of them versions of the MIPS microprocessor R3000. Hitachi is fabricating an embedded version of Hewlett-Packard's Precision Architecture Risc processor.

turers who have sought to introduce Risc-like features into the evolution of existing Cisc architectures with a view to achieving the sort of performances offered by Risc chips while maintaining compatibility with an accumulated software base. This is revealed in fig. 3 in the inclusion under Crisp of the latest microprocessors of the Intel 80×86 and Motorola 68000 families (i.e. the 80486 and the 68040 respectively) while previous generations are located under Cisc. Some observers prefer not to make the Crisp distinction, simply including these chips within the Cisc constituency.

3.2. Constituencies in the present evolution of the microprocessor industry

The total world's electronics market, including electronic equipment and components, has been estimated to reach $635 billion in 1991. Of these, $200 billion would be accounted for by the computer sector alone while semiconductors would take a share of $46 billion [23]. The same report put the market for micrologic or microsystems – which include general-purpose microprocessors, microcontrollers or embedded controllers and peripheral logic – at $9 billion for the year 1991, up 20 percent on the previous year. General-purpose microprocessors would account for about 20 percent of this very dynamic market whereas embedded controllers and peripherals would account for about 40 percent each.

It is possible to picture the "macro" industrial level of microprocessor as the ground for the evolution of three broad *architecture-based* constituencies i.e. Cisc, Risc and Crisp. A further sub-division take us to the level of product-family constituencies such as the transputer. In this pa-

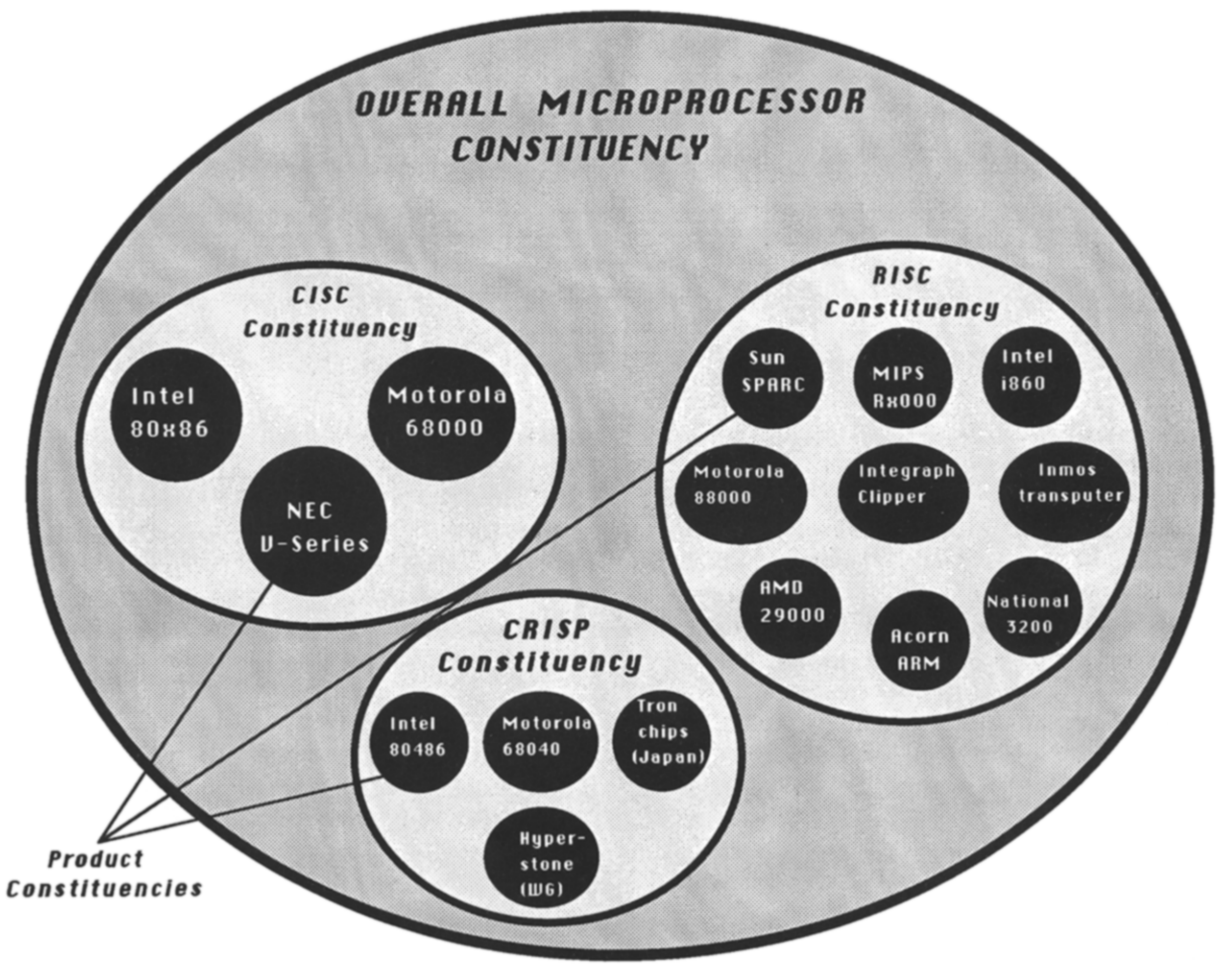

Fig. 4. "Micro"/"macro" constituencies in microprocessors: architecture-based case.

per, I take this level as the bottom "micro"-level. [8] Figure 3 identifies the basic parameters of this world of constituencies. In addition, fig. 4 tries to provide a graphical illustration of how these product-family constituencies are part of ever broader constituencies right up to the microprocessor-industry level of analyses. Both figures show, for instance, that some institutions such as Intel and Motorola have a presence in the competing Risc and Cisc constituencies or, what amounts to the same thing, these companies have become the ground for the evolution of competing and, as we shall see, probably conflicting constituencies.

3.2.1. Interaction and competition between Risc, Cisc and Crisp constituencies

Market shares are a manifestation of the relative strenght of the product-constituencies in an industry. In microprocessors, today, the strongest constituencies are by far the Motorola 68000 in microcontrollers and the Intel 80×86 in general – purpose microprocessors. These are the product-constituencies which at present control more than 90 percent of the combined market for these products. Shares, however, do not reveal the dynamism of the processes behind the numbers. This more interesting issue requires a "micro"/"macro" analysis which, specifically, locates the product constituencies into the evolution of the broader architectural constituencies of Cisc, Risc and Crisp.

Figure 3 and 4 illustrate who the main members of the Cisc, Risc and Crisp constituencies are. The key feature of their present evolution and interaction is the growing challenge of the Risc constituency to the long-established predominance of Cisc architectures in the market. In absolute numbers, Risc has a lot of ground to cover before catching up with Cisc. In 1990, for instance, some 500 000 Risc units were sold worldwide, which amounted to only half the 1 million Cisc units sold monthly by the Motorola 68000 alone [16]. In turn, Intel expected to sell some 7.5 million units of its best-selling 80386SX member of the 80×86 family during 1991. Quite clearly Cisc is the dominant constituency and exhibits a healthy growth. The Risc constituency, however, is making rapid market gains, coming out from a negligible presence in the mid-1980s to almost 10 percent of a $636 million market in 1988 and an expected 25 percent of a $1.7 billion market in 1992 [20].

The Risc constituency is growing fastest in the fastest sector of the computer market. This is workstations which was expected to top $10.3 billion in 1991, a growth of 30 percent on the previous year and well above the 12.4 percent average for the computer sector as a whole [23]. It was expected that Risc would displace Cisc (particularly the 68000 family) from its leadership in 1992. By then, the Risc constituency would have captured 42 percent of the market, against 37 percent for the 68000, 12 percent for the 80×86 and 9 percent for others. Another important development is the growing blurring of limits between workstations and PCs, specially as workstations are coming down in price. This is a direct threat to the stronghold of the 80×86 which is the dominant product-constituency in the PC market.

For the emerging Risc constituency not all the action is happening in workstations. Several Risc product-constituencies have already made chips available for the embedded control market. These include AMD's 29000 family which has been targeted for embedded applications, National Semiconductor's 3200 family which has been retargeted from workstations to embedded processing, the Intel i960, VLSI Technology's 86C010/20 which is based on Acorn's ARM and the Inmos transputer (the last two the European Risc architectures). As prices come down, the embedded control market is bound to grow in importance for Risc. Indeed, the sales of embedded Risc processors are expected to increase sharply in the early 1990s from around $35 million in 1990 to $250 million in 1994. And as this occurs, the proportion of units of microcontrollers sold by the Risc constituency is expected to increase much faster than that of general-purpose microprocessors.

It is this sort of growth combined to, indeed fueled by, the perception that Risc architecture has an inherently greater potential for performance, which is driving industry observers to

[8] The fact that some of the product-families have been licensed for independent development by different and competing semiconductor manufacturers means that sub-constituencies belonging to specific product-families have tended to appear. See note 7.

suggest that the trend is for the Risc constituency to take over from Cisc in the long run. In other words, the Risc constituency seems to be succeeding in the process of trend creation which will establish Risc as a shaping force within the overall industrial constituency. Indeed, on closer examination, this is already happening in the form of Crisp, which would basically amount to a recognition from the Cisc constituency that the Risc trend is already established. In this view, Crisp would be little more than an attempt by the Cisc constituency to adopt some of the features of Risc with a view to increasing its own range of performance, thus prolonging its dominance mainly on the basis of the accumulated software base. Of course, implicit in this step is an acknowledgement of the greater performance potential of Risc. Another indication that Risc is on the ascendancy comes from the fact that the dominant institutional constituents of Cisc, the companies Intel and Motorola, have both put Risc chips on the market (i.e. the i860 and the 88000 – see fig. 3), thus adding to the growing strength of the Risc constituency. Of course, the overwhelming dominance of Cisc in these companies is bound to create some difficulties for the expansion of the i860 and 88000 constituencies. After all, one has to take into account that the i860 was first designed as "a graphics and number-crunching supplement to the 486; then Intel's engineers realised that it could stand on its own, paving the way for Intel's entrance into the RISC workstation market" [29, p. 79]. This seems to be affecting the diffusion of the i860 since it has remained in use mostly as a graphics chip and not very much as a processor for RISC-based computers, which is were the greatest dynamism is taking place [6]. Similar difficulties seem to have affected the 88000 as "Motorola appeared to be competing against itself. Even as late as last year, the major workstation microprocessor of choice among workstation vendors was the Motorola 68000 family. That simple fact produced some scepticism in would-be customers of the 88000" [16, p. 38].

3.3. Related trends in the development of the industrial "macro"-constituency

A major influence in the development of the overall microprocessor constituency is the evolution of both semiconductor technology and systems markets (e.g. computers). As such I treat trends in these areas as an important part of the "macro" industrial level of microprocessors. Semiconductor technology, for instance, conditions and influences the strategies of the different product-constituencies through a combination of at least three major aspects:

(a) transistors budget (i.e. the quantity of transistors available to the microprocessor designer in a single piece of silicon at any one time);
(b) performance and on-chip functionality in microchip designs; and
(c) speed to market, development time, and R&D and production costs.

3.3.1. Transistor budget and Moore's Law

Transistor budget is a useful term used by Intel [35]. Back in 1964, Intel's chairman and co-founder Gordon Moore, then director of research at Fairchild, predicted what has become known as Moore's Law, namely, that the complexity of integrated circuits would continue to double every year [53]. At present Moore's Law has slowed down from one year to about 1.5 years for DRAM memory semiconductors which are leading this trend towards greater integration given their simpler, regular patterns which allows for more transistors to be packed onto silicon. [9]

In microprocessors, the scale of integration has always lagged behind that of memory. The much greater complexity of circuit designs generally translates itself into less density of components per given silicon area. Unlike DRAM memories, the time scale is two years for a doubling of the number of transistors per chip. At present, microprocessors have reached 2.5 million transistors with the Risc i860 XP from Intel [27]. Over one million transistors chips began to reach the market around three years ago. These are the Motorola 68040 having 1.2M and the Intel's chips 80486 and i860 having 1.2M and 1M respectively. Intel has suggested that by the year 2000, it is

[9] For instance, the first samples of 4-Megabit DRAM chips were introduced in 1988 while the first samples of 64-Megabit chips are expected to be introduced in 1994. This would mean a lapse of 6 years for a fourfold doubling of the number of components in the chips [4].

possible that what they have called the Micro2000 may have as many as 100 million transistors. This would be 80 times as many as the present i486 and 40 000 times as many as the first 4004 microprocessor created by Intel in 1971.

3.3.2. Performance and on-chip functionality in microchip design

Such a large transistor budget will pose a real challenge to microprocessor designers. So far, this has not been a problem since there is plenty of logic which designers would want to put on chip. But, by the middle of the 1990s, industry analysts envisage microprocessors with about 8 million transistors; a level of density at which "existing architectures will be nearing their performance limits" [61, p. 66]. The problem at 50 to 100 million transistors is strikingly illustrated by G. Moore: "we could put every logic chip that's ever been built on one chip" [14, p. 26].

The impact of these dramatic gains in transistor integration has been equally dramatic gains in *performance* and *on-chip functionality*. Take the performance gains of Intel's Cisc microprocessors over the years. Since the original Intel 4004 microprocessor 20 years ago, performance in MIPS (million instructions per second) has increased almost 280 times from 0.09 to 25 MIPS for the i486. Further ahead, for the Micro2000, Intel is envisaging a performance of 2 billion instructions per second. This would be a chip 80 times more powerful than today's i460.

These dramatic developments in microprocessors performance are well matched by some trends already visible in the evolution of on-chip functionality. In particular, a transistor budget of tens of millions is transforming the silicon chip into a sort of electronic "black hole" which is "swallowing" more and more of the functionality found before in chip sets and electronic boards. Of course, this has been a trend from the early days of the integrated circuit but now the point is rapidly being reached where the predominance of a single processor on chip will be superseded by the inclusion of several CPUs (sometimes of different architectural designs) and much of the accompanying logic for whole systems such as personal computers. For instance, Intel is talking of having "a single-chip PC equivalent to an IBM AT Model 339 by 1993" [7, p. 132]. For the 100-million-transistor Micro2000, Intel envisages a high-performance option which would incorporate 4 CPUs executing instructions in parallel and each running at 700 MIPS to give a total chip performance of over 2 billion instructions per second (BIPS) [7,35].

3.3.3. Speed to market, development time, and R&D and production costs

The overall microprocessor constituency is extremely dynamic. Suffice to look at the speed with which succeeding generations of chips within the same product-constituency have been reaching the market. In the case of Intel, the pattern is for a new and more complex microprocessor almost every three to four years, with several higher-frequency or cheaper variants in between. The pattern shown by the Motorola 68000 is rather similar with two to three years in between successive generations of the family. In addition, the shorter experience of the Risc constituency tends to confirm this rather dynamic evolution of the microprocessor industry. For instance, MIPS Computer Systems has launched its R4000 microchip, the third member of the family since its debut on the market in 1987. This would make it a new microprocessor almost every two years.

Underlying this high degree of dynamism is a continuous race to shorten product development time, including debugging (i.e. the elimination of defects in the products). For instance, "Since 1985 Intel has cut chip development time by more than half, to an average of 44 weeks. The lead time for the 486 was shorter than for the 386, even though the new chip is a lot more complicated" [29, p. 80].

Obviously this kind of results is not likely to be achieved on the cheap. Hence it is not surprising to find that the shortening of development time has gone hand in hand with an increase in development and production costs. Intel's production costs for each successive generation have gone up from the $60 000 for the very first 4004 microprocessor to $250 million for the 486. Estimates by Intel suggest that to build a state-of-the-art manufacturing facility would amount to $400 million in 1990.

It is interesting to note that the trend towards huge and increasing development and production costs exhibited by Intel is not accepted by some companies particularly from the Risc constituency. T.J. Rodgers, President of Cypress Semiconductor and a leading critic of Intel's approach, has argued that for $7 million his company developed a five-chip set that is four times more powerful that Intel's 80486 [22, p. 84]. If Rodgers is right then ever-increasing development and production costs will cease to be important barriers to entry into the microprocessor industry. As for production costs, however, the evidence for Rodgers' point is not that clear. If the trends in the leading memory semiconductor sector have anything to say to microprocessors, the fact is that the cost of manufacturing facilities is increasing dramatically as the technology moves ever-down towards the 0.1μ level of definition.

3.3.4. Systems markets trends

In terms of system markets, we have broadly classified microprocessors into two main types: embedded controllers or microcontrollers and general-purpose microprocessors. These two sectors show very distinct requirements. For instance, embedded controllers are preprogrammed, so this sector has low dependency on system software and applications software portability (i.e. the capacity to move the software from one machine environment to another). A more important overall feature would be the ability of the components to provide for easy-to-design systems with low development and manufacturing costs. On the other hand, the programmability of GP microprocessors makes this sector heavily dependent on software capabilities such as portability, inter-operability (the capacity to interconnect systems from different suppliers) and support for standards. This is at the heart of one of the most important trends already at work in the computer market, namely, the move towards open systems among buyers of computer systems [3]. In addition, the specific trends and requirements vary from the PCs and Low-end Workstations segment to the High-Performance computing segment. Thus, the PCs segment has a much stronger requirement for standard system level software and compatibility with existing systems. In particular, application software portability from the systems environments of the systems leaders is critical. Of course, given the permanent gains in microprocessor performance, it is also worth noting that the limits separating the two segments are being blurred all the time with PCs and high-performance workstations moving into each other markets.

This trend towards openness and away from proprietary systems has another expression in the systems companies' preference for second-sourcing of microprocessors. Second-sourcing reduces the risk of depending on a single supplier for a critical technology and, also, is likely to stimulate competition with potentially favourable effects on costs.

4. Risc versus Cisc: Constituency-building strategies and the establishment of the Risc trend

The battle of Cisc versus Risc is the battle of an emerging constituency versus a powerful established constituency dominating the market. The greatest burden is undoubtedly on the shoulders of the emerging constituency. All the more so in the case of the Risc constituency which has hardly been able to spearhead its growth on the basis of a free or new segment of the systems market. Three major criteria have been identified for the successful take over by new microprocessor architectures: "new architectures will need significant performance gains (or cost advantages) over others, backing from a credible vendor, and the right technical and business climate to encourage users to switch" [22, p. 66].

Of course, in the Risc versus Cisc case this is not a straightforward matter since for every claim by the emerging constituency one would expect a counter-claim by the established constituency. Indeed, this is precisely what the institutional core of the Cisc constituency is doing with such announcements as the Micro2000 which are offering a long-term path of continuous and compatible upgrading in Cisc performance. On these grounds, therefore, a great deal of difficult relative judgement is involved, particularly, by the current users of the Cisc constituency who need to ponder the advantages of joining the new emerging constituency in circumstances which may not be totally clearcut given their investments in Cisc.

The fact is that this is a very complex process which is bound to involve many "micro"/ "macro" factors. Technical, legislative, economic, personality factors, etc. they all come into what is basically a battle for the minds and hearts of people, particularly, institutional strategists and decision-makers. Critical in this process are the strategic limits and opportunities implied in the nature of microprocessor technology itself. As a *component technology*, for instance, microprocessors can only realise their purpose by being integrated into end-product systems. This means that the users to target for constituency-building are the systems companies and not the general consumer. It simultaneously means that consideration of the requirements of these systems companies becomes an important element in the development of specific microprocessors. Second, microprocessors are a technology with indirect *network externalities* in that their benefit to the users (and hence their likely pattern of diffusion) entail the provision of a complementary good: software [25,38,39]. [10] This means that constituency-building for new microprocessors normally has to deal with a well-recognised "Catch-22" situation, namely, users will not commit to a microprocessor until enough software is written, but software developers will not write the software until enough users have adopted the microprocessor [21]. Third, microprocessors are also what I define as *architectural technologies*, that is, technologies which in the course of their existence may evolve through several product-generations in a way which combines substantial change with continuity or compatibility. Their most distinctive feature is an accumulation and portability of software, which go hand in hand with major advances in hardware. For constituency-building, the implication is that decline needs not follow the first generation product. With architectural technologies, new generations actually seek to build upon the technical and social constituents of the previous one, thus re-generating the momentum of the constituency. At the same time, the capacity for major change from one generation to another provides an opportunity for equally significant changes in the constituency-building strategies pursued by the originators of the technology. In particular, as we shall see, there is ample opportunity to change radically the balance between collaboration and competition, expressed through arrangements such as licensing and second sourcing. Fourthly, microprocessor are technologies based on codified knowledge which can be more easily reverse-engineered or copied by competitors. This means a weakness in the appropriability regime determining a company's ability to control, or fully appropriate, the commercial benefits of a successful product [63]. [11] In terms of constituency-building, the implication is that those companies seeking to monopolise the benefits of successful microprocessors will most likely have to resort to a strong use of legal instruments (e.g. patents and copyrights) to try to fend off cloners.

Below, we shall see how these features implied in the nature of microprocessor technology have played an important part in the constituency-building strategies implemented by the Cisc and Risc constituencies. In particular, at this early stage, they have been exploited to help shape current perceptions or visions about trends in the industry. For the emerging Risc constituency this has been specially important; for, if Risc is ever going to displace the overwhelming dominance of the established Cisc constituency, it is clear that the perception must precede the fact. In other

[10] "indirect externalities [are] associated with the provision of a durable good (hardware) and a complementary good or service (software)...the externality arises when the amount and variety of software available increase with the number of hardware units sold. For instance, computers and programs must be used together to produce computer services, and the greater the sales of hardware, the more the surplus the consumer is likely to enjoy in the software market due increased entry" [38, p. 146]. In Teece's words, software is a specialised complementary asset to the hardware [63].

[11] "A regime of appropriability refers to environmental factors, excluding firm and market structure, that govern an innovator's ability to capture profits generated by an innovation. The most important dimensions of such a regime are the nature of the technology, and the efficacy of legal mechanisms of protection" [63, p. 287]. As far the nature of technology is concerned, Teece defines product, process, and tacit and codified knowledge as key dimensions; whereas patents, copyrights and trade secrets are the key dimensions regarding legal instruments. Thus, a technology which is based on codified knowledge is likely to have a weak appropriability regime since it can be more easily copied than one based on tacit knowledge which by definition is difficult to articulate. Patents do not always guarantee perfect appropriability because many can be "invented around" at modest cost. When the innovation is embedded in processes, trade secrets are likely to provide better protection than patents.

words, the perception that this displacement *will take place* must first take root within the overall microprocessor constituency. In contrast, the established Cisc constituency needs to re-create the perception that it is and will remain the dominant trend for the future. Let us see how this is actually happening in the Risc and Cisc constituency-building strategies.

4.1. The hardware battleground

In hardware, the architectural-technology nature of microprocessors comes to mind immediately, particularly in relation to both constituencies' progress in speed of product development and the level of integration in successive generations of hardware. There is an interesting fact here in that both the Cisc and Risc seem to be keeping pace with each other. In particular, we have seen that both Intel and Motorola have joined the Risc constituency thus making available to it the same sort of advanced production facilities enjoyed by the 80×86 and 68000 families. Thus, until recently, the Cisc constituency was ahead with a level of integration of 1.2 million transistors against the 1-million Risc i860 also from Intel. Now, Intel has launched the i860 XP which contains 2.5 million chips, thus putting Risc ahead once again. In addition the i860 is a 64-bit microprocessor family while the latest Cisc i486 is a 32-bit chip. The same company, however, is promising the Micro2000 Cisc chip with 100 million transistors for the year 2000 and so on and so forth. Obviously, this Cisc versus Risc competition inside Intel most graphically illustrates the fact that hardware-wise Risc and Cisc are holding on to each other's challenges. But other companies are also involved in the same process as the evolution of the entire microprocessor constituency is seemingly being shaped by the continuous prevalence of the Moore's Law. Consequently, it seems that hardware is not the ground where the most decisive battles in trend creation are taking place. Another reason is that "the software industry always moves behind the hardware industry" [10, p. 18], and there can be a considerable time lag between a new chip and the availability of software which exploits its capabilities. The result is that the take up of new chips by the market may proceed fairly slowly. For instance, a report found that, after 18 months of the launch of the latest i486 chip by Intel, the penetration of the PC market had been minimal, with 486 PCs actually accounting for less than 1 percent of the total PC market. The report also suggested a compounding cause: the proliferation of microprocessors which is giving users too wide a choice and may be leading to a slowdown in the process of diffusion of new chips.

4.2. The software battleground

The Cisc versus Risc challenge seems to rest not as much in hardware as in the specific constituency-building strategies pursued by the members of each constituency, particularly, in relation to software (network externalities) and policies towards the proprietary control of the technology (appropriability regime). It is here where a sharp contrast between Risc and Cisc can be easily identified and where the Risc constituency seems to be scoring high in the process of pro-actively trying to establish itself as a major industrial trend for the future.

It is highly illuminating to compare in detail the strategies of the companies which are leading the play in both constituencies. In the Cisc constituency the situation is clear with Intel and Motorola as the undisputed leaders. In the Risc constituency the situation is different, but there is general acceptance that it is the US companies Sun Microsystems and MIPS Computer Systems who have been the most aggressive in their Risc constituency-building strategies. We have seen before that, inside Intel and Motorola, Risc was growing under the shadow of the Cisc constituency, and this was having some effect in the diffusion process of the i860 and the 88000. This is not the case with Sun and MIPS who have gone all-out to promote Risc. Not surprisingly, even Motorola's Risc marketing manager, Jeff Nutt, is quoted as saying: "We are not in the evangelistic style of some of the others" [16, p. 38]. From our point of view, however, it may be precisely this "evangelistic style" which may be paying off for the Risc constituency and which, indeed, may be very much required in the early phases of the constituency-building process, specially when the arena is heavily dominated by a powerful competing constituency.

In software, the Cisc versus Risc challenge is being fought all over: microcode, [12] operating systems [13] and applications software. [14] Each one of these areas is the subject of policies and developments which, put together, provide the constituencies with a mixture of mechanisms to gain or keep control of the development of the overall microprocessor industry and market. For the Cisc constituency dominating the industry, the natural goal is to try to keep it that way. Whereas for the Risc constituency, there can be hardly any other goal than to break the stronghold of Cisc. In software, this difference becomes crystal-clear insofar as leading players of both constituencies are following completely different, almost opposite, strategies. As we shall see, however, these differences are quite consistent with the present relative strength of both constituencies at the "macro" industrial level of microprocessors. For instance, leading Cisc constituents are in a position to use already established industrial trends to try to reproduce, as well as profit from, the current Cisc-dominated market. Whereas, for Risc, the whole enterprise is about trying to establish itself as a "macro" industrial trend.

4.2.1. Microcodes and licensing strategies

Microcodes have furnished one of the most contested areas of control, with Intel, in particular, initially licensing for second-sourcing, and then trying to establish legal protection and monopolistic control over their 80×86 family microcodes. The "architectural" and "codified-knowledge" nature of microprocessor technology is quite important here, because it has clearly conditioned the evolution of the specific strategies of different players. Intel's current rationale is that a "state-of-the-art microprocessor can cost hundreds of millions of dollars to develop. Companies cannot afford to invest that kind of money in a product that can be copied" [22, p. 116]. This seems fair as far as it goes but the situation is more complicated, since Intel has indeed stopped licensing their chips altogether in a big shift from its initial second-sourcing policy geared to promote the build-up of the 80×86 constituency. Furthermore, in complete contrast to Intel and Motorola, Sun and MIPS are both promoting second-sourcing of their respective architectures: the SPARC which was originally conceived at the University of California, Berkeley, and the MIPS which is based on work done at Stanford University. Of course, the key point is that the Intel 80×86 and Motorola 68000 architectures are the dominant force in the market. Thus, by not licensing, the companies are just trying what is indeed a common event in market economies, namely, to reap premium profits through the establishment of monopolistic control over winning products. What is interesting, however, is that, with its 80286 chip, Intel did not follow the model of reaping monopolistic advantages by being first in the market with no imitators. Instead, the company deliberately promoted imitation (by licensing for second-sourcing to AMD in 1982) of the 80286 chip, as a way of speeding up the build up of the 80×86 constituency in the face of Motorola 68000 competition [34]. Then, with the launch of the next generation 80386 chip, Intel was able to reverse completely this licensing policy, trying to exclude imitators from future gains, while still building on the constituency (software, users, etc) established with their help during the previous generation. In this process, Intel has certainly exploited the opportunities implied in the architectural nature of microprocessors to try to lock in buyers to its own supply. And quite understandably too, after all, by licensing the 80286 to AMD, Intel learned that they could easily lose control of the market for chips of their

[12] The definition of microcode is by no means a clearcut matter. This is especially true from a legal point of view with its implications for copyright protection. The following definition of *microcode* has been suggested, "a set of operations (microinstructions) that defines or executes the macroinstruction set of a microprocessor, where the different macroinstructions are defined or executed by somewhat overlapping subsets of the whole microinstruction set... Thus, the function of microcode is to implement instruction sets in hardware" [62, p. 82].

[13] *Operating system* is a "program that manages a computer's hardware and software components. It determines when to run the programs, and controls peripheral equipment such as printers" [30, p. 158].

[14] *Applications programs* are the users' software. It enables the computer to be applied to countless specific tasks which are of the interest of users. Applications programs are written in high-level languages and make direct use of operating systems. "Operating systems provide a set of procedures that a program can call (the set is known as an application programming interface, or API), and when one of these is used information often has to be passed (on the stack) either to the operating system or back the other way" [31, pp. 52–53].

own creation. With the 80286, AMD eventually ended up with 52 percent of the market against Intel's own 33 percent [5]. Now, Intel's approach is to lock in buyers to its own supply.

As expected, however, imitators of the 80 × 86 architecture are not standing idle in the face of Intel's onslaught, they are indeed responding by taking advantage of the opportunities to copy implied in the weak appropriability regime and codified-knowledge nature of the technology. As a result, the evolution of the Cisc constituency has been marked by some famous court cases in which Intel has sought to lay legal grounds for the control of its chips. A crucial case was the Intel versus NEC microcode case in which Intel accused NEC of having copied the 8088/8086 microcode and used it in the NEC V20/V30 microprocessors. In this case, the very definition and status of microcode was at stake, in particular whether it was subject to copyright or not. The court eventually decided that microcode was a computer program subject to copyright, thus making it illegal for other companies to copy microcode. However, the ruling also accepted that it was legal to emulate microcode, that is, reproduce its functionality while avoiding its particular expression [22]. In this respect, the court found that NEC had not actually copied Intel's 8088/8086 microcode. Thus, both companies actually won. NEC was able to continue to imitate and Intel was left with a legal weapon to try to tighten control of the 80 × 86 product-constituency.

Subsequently, the copyright law has been used by Intel against AMD since, as indicated, AMD has not given up on the 80 × 86 family, and have produced a 386 clone which they took two years to reverse-engineer [5]. Intel sued AMD, arguing that the clone uses the Intel microcode which AMD should not resell beyond the 286. AMD countered that the previous agreement gave them the right to use the microcode. In the meantime, another Silicon Valley company, Chip & Technologies, also unveiled a version of the 386 chip, prompting an immediate patent infringement suit by Intel. Chip & Technologies claimed that their chip is an emulation and not a copy of the 386 [28]. Both cases will be settled in court, underlining Intel's difficulties to enforce monopolistic control over its technology when imitators can take advantage of its codified-knowledge nature. But Intel is not just relying on the courts, it is also moving fast along the architectural-technology path of microprocessors. The company has put out its 1.2 million-transistor 486 which should prove much more difficult to reverse-engineer than the 275 000-transistors 386. For AMD, however, this is a matter of survival and they are expected to release their 486 clone by mid-1993. As the level of integration is on the increase, however, AMD may find it increasingly difficult to catch up with Intel in its efforts to remain an important member of the 80 × 86 constituency.

The conflictive and monopolistic-oriented control of the microcode exhibited at present by the dominant Cisc players contrasts strongly with the open-licensing constituency-building policies adopted by Sun and MIPS, the leading players in the Risc constituency. Of course, it is a fact that, for Risc, the "lock-into-a-single-supplier" approach hardly constitutes a path for rapid accumulation at this early phase of constituency-building. I think that this has been clearly illustrated, for instance, by the experience of Hewlett-Packard's Precision Architecture which was one the first Risc architectures to be developed. It was kept proprietary and the product-constituency has never gathered the sort of momentum achieved later by the open-licensed SPARC and MIPS architectures. Later, Hewlett-Packard changed this policy and has licensed Precision to Hitachi [3]. Further evidence comes from the Intel i860 and Motorola 88000, for, besides the difficulties posed by the strong Cisc presence in the companies, Intel has also kept its i860 Risc architecture proprietary, whilst the Motorola 88000 has been second-sourced only for military applications. In fact, Motorola has attempted a different process of constituency-building, by forming the 88Open consortium of hardware and software suppliers with a view to setting standards for compatibility between all systems based on the 88000. Motorola claims that some 21 companies are using the 88000 and that there are on the order of 2000 application packages available. In practice, only six US manufacturers are thus far using it in general-purpose computing systems [16].

Clearly, the proprietary approach has not proved the most dynamic for Risc. And this is not surprising because this constituency is emerging into a "macro" industrial level created by a competing Cisc constituency strongly buttressed behind the advantages conferred by indirect network externalities. Thus, licensing and alliances do make sense for the upstart companies leading the Risc constituency [20]. They simple need to stimulate the rapid development of both *technical and institutional constituents*, if their Risc architectures are ever to become trends effectively shaping the development of the overall microprocessor constituency. These are certainly the lessons of the very successful constituency-building processes of computer architectures such as the IBM 360/370 and the systems based on the 80×86 itself. These product-constituencies successfully established themselves as industrial standards on a spate of cloning which encouraged their diffusion widely.

As indicated, Sun and MIPS are the companies which have done the most to license their respective Risc architectures in order to establish them as de facto standards within the general Risc trend. Important to this process has clearly been the disaffection of many semiconductor companies with Intel's and Motorola's decision not to license their dominant Cisc architectures. It created a pool of suppliers ready to be exploited by an emerging Risc constituency willing to second-source. A brief comparison shows that Sun has licensed SPARC to several semiconductor companies, including LSI Logic, Bipolar Integrated Technology, Cypress Semiconductor, Fujitsu Microelectronics, Texas Instruments, Philips, and Goldstar. In turn, MIPS has licensed the R3000 for mass production to six semiconductor companies including NEC, Siemens, and Sony. Also important to the process has been Sun's and MIPS's decision not to manufacture or supply the chips, but to concentrate on using them to produce their own workstations, while collecting royalties from the semiconductor companies selling them. This usage-led strategy is clearly consistent with an open-licensing policy. Workstations are subject to the Catch-22 situation implied in the dependence of hardware on software (network externalities). Thus, by promoting multiple-sourcing of the microprocessors, a more rapid development of software may be expected, which, in turn, will help the SPARC and MIPS systems to become *de facto* standards in the workstation markets.

The overall results have been quite good for both the SPARC and the MIPS's $R \times 000$ (Rthousand) product-constituencies. A recent report put at 29 the number of companies offering SPARC-based systems; whilst 22 companies are using the R2/3000, including DEC, NEC and Tandem [16]. Ahead of the constituency-building race is Sun – and not just in terms of institutional constituents but, also, in terms of technical constituents where SPARC boast the largest number of software application packages – some 2500 according to the highest estimates. In addition, Sun is by far the leading workstation vendor (with around a third of the market) which can only reinforce the progress of the SPARC constituency. Sun is also taking steps to maintain compatibility between the products of all SPARC constituents. There is the danger that licensees may fragment the constituency by producing SPARC-based chips which are incompatible with each other. Thus, Sun has helped set up SPARC International, an organization of manufacturers which tests for software compatibility and has a role in the evolution of the SPARC hardware standard. "SPARC International is an independent, nonprofit association, but few would dispute that Sun controls its purse string" [15, p. 46]. Uniquely, however, Sun has turned over the rights to SPARC to the SPARC International Consortium with the result that SPARC is not just multiple sourced and has multiple architecture implementations which aim for compatibility with each other. SPARC would also be openly owned and controlled by the Consortium. In addition, Sun has created the company SunSoft Inc. in an effort to enhance further the image of openness. SunSoft will provide the operating systems software, both to Sun and other companies. In principle, Sun will be a customer to SunSoft just like any other member of the SPARC constituency.

In contrast to Sun, MIPS has stimulated multiple second-sourcing but has kept control of the $R \times 000$ architecture. MIPS' strategy, however, has been even more aggressive in recruiting licensees to produce the $R \times 000$. Thus although the company lacks the advantage of Sun's leadership in the workstation market, it looks like the policy of rapid build up of the constituency has been quite successful. For instance, it was estimated that MIPS licensees would ship around 100000 chips in 1989 against shipments of 50000 chips by Sun's licensees. MIPS also run an organisation, Synthesis Software Solutions Inc., for compatibility and for acquiring, porting, supporting and distributing third-party software for the chips from different licensees. Until 1990, it was a separate organisation but now is under the fold of MIPS. This has provided ammunition to those who argue that "MIPS's architecture is also second-sourced but the microarchitecture is tightly and solely controlled by MIPS Inc." [60, p. 10]. In practice, however, this has not been a problem for the rapid build-up of the constituency stimulated by the open-licensing policy. Indeed, in April 1991, MIPS made big news when 21 computer manufacturers formed the Advanced Computing Environment (Ace) consortium with a view to establish a standard advanced computing architecture around the MIPS latest 64-bit R4000. One of the leaders of the consortium is Compaq, a top 80 × 86 constituent. Other companies include software developers Microsoft and Santa Cruz Operation and computer manufacturers DEC, Unisys, Control Data, Olivetti, Siemens and Sony. Ace is not completely settled, however, and some members of the consortium are expected to "bring out workstations products based on other Risc architectures, a move that could undermine or dilute their commitment to Ace" [12, p. 4]. Time will tell but Ace products were expected to begin to reach the market around mid-1992.

4.2.2. Operating systems and applications software

The greatest strength of the Cisc constituency is the huge base of applications software accumulated over the years for their architectures. This network externality is the key to Cisc's domination of the "macro" and hence, resilience as a major industrial trend. Applications programs are the technical constituents which link users to an specific computer architecture and, consequently, to a microprocessor constituency. Huge investments by users and a wide range of available functionality provide the Cisc constituency with a formidable defense and, indeed, shaping force [21]. The scale of this Cisc defense is simply enormous. The 68000 family alone has a $3 billion software base attached to an estimated $100 billion worth of hardware [9]. Whereas Intel's hold of the PC market has meant an accumulated $40 billion worth of software for 80 × 86-based systems sold since the early 1980s [29]. And, of course, all this software is highly portable not just among all the different chips of the 80 × 86 family but also among all the different makes of 80 × 86-based PC systems, precisely because of the common architecture and binary compatibility. As G. Moore put it, "Compatibility is one of the most important reasons that Intel microprocessors are being used so broadly throughout the world. Our commitment to an upwardly compatible family was clearly important" [22, p. 95].

The software base of the Cisc constituency is far beyond what the Risc constituency has at present on offer. Yet, we know that the speed of the build up of the Risc constituency among users clearly depends on the development of its software base and vice versa. This Catch-22 situation must be broken by Risc (it is simply a pre-condition to breaking the total dominance of Cisc), by attracting many software and computer suppliers and users who are currently exclusive members of the Cisc constituency. This seems now to be happening as many big names including Intel and Motorola have joined the Risc constituency. Indeed, all major semiconductor and computer companies belonging to the Cisc constituency have recently become members of the Risc constituency too. This includes computer manufacturers such as DEC, Unisys, Data General, Control Data, Hewlett-Packard, Compaq, Apple, Siemens, Groupe Bull, ICL, Fujitsu, NEC, Hitachi, and above all IBM. Critically, the large software developers such as Microsoft Corp. and Lotus are also jumping into the bandwagon and adding to the momentum. For instance, Microsoft is expected to adapt OS/2 (the new IBM operating system) and Windows to run on Risc. And, as part of its participation in the Ace consortium, Microsoft is also expected to deliver by 1993 a critical technical constituent for Risc: software which will port MSDOS-compatible applications programs onto R4000-based systems. This means that much of the applications software for the 80 × 86-based machines will also be able to run on machines based on the MIPS's R4000 chips [6]. If and when this materialises, the software advantage of the Cisc constituency will be seriously undermined.

In this process, the key factor in favour of Risc has been its ability to relate to users' long-term needs by means of, on the one hand, the perceived inherent advantage of Risc in terms of cost/performance and, on the other, Risc's close association to open systems through multiple-sourcing and the use of Unix as standard operating system. With open systems in particular, Risc has been positively responding and contributing to a well-established trend in the computer market (see section 3.3.4 above). In so doing, Risc seems to be exploiting much better than Cisc the opportunities and limits implied in the fact that microprocessors are component technologies to be used in systems. Earlier on, I pointed out that, with component technologies such as microprocessors, the requirements associated with emerging or established trends in major systems markets should be treated as an important part of their (the component's) "macro" industrial level. This is exactly what Risc seems to be doing, in clear contrast to Cisc and its strongly monopolistic approach. This responsiveness to users' long-term needs seems to be bearing fruits for Risc.

Thus, in terms of cost/performance, although it is recognised that only an accumulated base of software will truly materialise the advantage of Risc, the systems companies' perception that this advantage is most likely to prevail in the long run has gradually spurred software and systems developers to increase their support for Risc. In terms of open system, the fact is that Risc and Unix have been mutually reinforcing each other's growth. [15] Risc has been growing fast in the scientific and engineering workstation market where Unix is *de facto* standard; whereas Unix has reinforced this position as *de facto* standard as a result of Risc's cost-effective performance. Recently, the rapid growth and falling costs of workstations are further stimulating this process by threatening a Risc expansion into other segments of the computer market at present in hands of the Cisc constituency. Established Cisc computer manufacturers and software developers have been left with little option but to take notice of the Risc challenge – and they are joining the Risc constituency in a big way.

A closer look at the open-systems role of Unix shows that it is based on two factors. First is the ready availability of the operating system to everybody. Second, unlike the situation in the PC arena where applications software is closely linked to the microprocessor architecture, most Unix applications software – because it is written in the C high-level language – is relatively easy to port between different architectures once a good optimising compiler is developed for a new architecture [20, p. 64]. This high-degree of application software portability is precisely what users want, and Risc and Unix are giving it to them.

The Risc constituency's ride on Unix, however, is not free of problems. In particular, Unix is not a single operating system. There are many versions of it as, over the years, suppliers have taken advantage of its easy access and adaptability to modify it to suit their requirements. For instance, Sun and MIPS are running different versions of Unix. This means that although applications software can be ported between different architectures running the same Unix version, the same applications software cannot be ported to computers running a different version of Unix. This has conspired against a rapid accumulation of applications software because it has fragmented the Unix market, increasing the costs of software developers who find that they must create different versions of the same software if they want to cater for the market at large. In this respect, operating systems such as MS-DOS and OS/2 are single products and have the attraction that the same version of a program will run on all the PC systems using them. Fortunately, for the Risc constituency, the different Unix factions seem to be coming to an understanding towards a single Unix standard. The two major camps: Unix International Inc. headed by Unix's creator AT&T and Open Software Foundation (OSF), which include IBM, are in negotiations which observers believe will remove the stumbling block of Unix fragmentation [13]. Of course, any such process will take some time to complete but this is the direction where the computer users' increasing pressure for open systems is certainly leading.

Central as it is, the Unix approach is only part of the complete software strategy being displayed by the Risc constituency in its effort to breach the buttress of network externalities underpinning Cisc's dominant presence at the "macro" industrial level. The other major part sees the Risc constituency clearly being shaped by the force of Cisc's accumulated software: Risc is trying to port

[15] "... most of the concepts for RISC originated not from groups working on CPU design, but from software groups aimed at developing advanced software compilers optimized for implementing such high-level languages as C" [20, p. 64]. C is the language of Unix.

Cisc software to run on Risc hardware platforms. Thus, we have seen that already other standard operating systems such as OS/2 and windowing standards such as Windows are in the process of becoming part of the constituency. Most crucially, the Risc constituency is targeting the accumulated base of MSDOS-compatible applications software which is the key strength of the 80 × 86 product-constituency. The goal is to develop software interfaces which would allow Risc constituents to tap into the billions worth of accumulated Cisc software by virtually freeing it from its close attachment to the Cisc architectures. To use Katz and Shapiro's words, Risc is unilaterally acting to make its product compatible with those of Cisc by constructing an adapter [38]. The Ace consortium, for instance, is said to have chosen MIPS's R4000 mainly because of its architecture which makes it easier to run this MSDOS-compatible software. Ace's intention is to develop application programming interfaces based on various versions of Unix which will allow applications to run on R4000 systems as well as IBM and compatible PCs [11]. This would make MS-DOS applications software "architectural neutral" (i.e. the software could adapt itself to different machines) in relation to R4000-based systems. But others are following the same path with the result that the "architectural neutral" approach is becoming quite promissory for the Risc constituency. In this process, the OSF is playing a leading role with its Architecture Neutral Distribution Format (ANDF) which would allow the distribution of software in a form that could be run on any system equipped with another piece of software called installer [3,55]. In Europe, the transputer and the ARM constituencies are pursuing the OSF's ANDF and a similar approach called VBI (Virtual Binary Interface). Both are seen as a significant improvement in the process of enabling existing software to be ported to new architectures. It is considered a "proven technology, about to become commercially exploited, and it is also a technology in which Europe has a technical lead" [24, p. 25]. Clearly, ANDF and VBI are critical technical constituents to the Risc constituency's efforts to break the industrial dominance of Cisc. Whether it is round the corner, one shall soon be able to see, but certainly the Risc constituency believes that 1992/1993 will see these products becoming available.

As progress is made in the Unix and applications-software fronts, Risc is bound to benefit from an increased number of applications programs. This will make the constituency a much more formidable contender in the PC market currently dominated by Cisc. But, the Cisc constituency is not standing idle, just waiting to see Risc taking over as the leading force in the development of the overall microprocessor constituency. Intel and Motorola are also trying to maintain the initiative and not just relying on the buttresses of their accumulated software base, after all we have seen how Risc strategies are being shaped to counter this specific Cisc strength. What Intel and Motorola are also doing is battling hard to counteract one of Risc's main weapons, namely, the perception that Risc is superior to Cisc in performance. Intel, for instance, is producing competitive chips such as the Intel 486 and there is the promise of a clear compatible path of ever increasing performance leading to the Micro2000. It is clear that, by unveiling such a long-term path of software compatibility and competitive performance, Intel is hoping that the 80 × 86 constituency will be able to beat Risc at its game. Intel is telling users that the trends in semiconductors are such that the 80 × 86 will have all the silicon it needs and more to keep up with the performance race. Intel's chief executive officer, Andrew Grove is promising: "We are going to outperform everything anybody else will offer" [6, p. 55]. The message is clear: there is no performance reason for users to change to Risc and total compatibility right up to the Micro20O0 is the best way to protect their software investments.

Thus, the performance/software battle is by no means a clearcut affair in favour of one or the other constituency. Rather a more deciding factor will be the ability of both constituencies to relate to users' long-term needs. Here, the main issue is whether systems companies will want to depend on tightly proprietary architectures and single-sourcing, or they will definitely want greater architectural independence and multiple-sourcing. The present trend towards open systems in the computer industry suggests that the second option is most likely to prevail in the long run. Not surprisingly, some observers are already predicting a decline in Intel's and Motorola's hold within the microprocessor industry. "It is Intel's and

Motorola's dominance and monopoly position in the Cisc market, unpopular among large users for many years, which is now threatening their position. Intel has tried to fight back... but its customers are increasingly attracted to multiple sourced risc chips" [12, p. 14].

This is consistent with the predictions of top IT industrialists. Specifically DEC's president Ken Olsen envisions the customers' drive towards open systems leading to what he calls "networked enterprise-wide computing". They want "transportable software, and they want all their computers to run on a network, no matter who makes them... They want flexibility... They want to have a choice of Apple, Digital, IBM, Unix, OS/2, or whatever they want' [22, p. 76]. In this world, the application software is transportable, the system and software run on an enterprise-wide network, and the CPU runs any operating system on the desktop. Proprietary CPUs no longer will have such a controlling influence and they would be optimised to suit particular applications [22]. Then, we would see a much more pluralistic future in which Cisc and Risc will most likely exist side by side even in the same piece of silicon. Moreover, even further into the future, "a new crop of architectures will emerge that will displace those in use today" [61, p. 66]. What is clear is that the evolving world of microprocessors has not seen the last with the current struggle between the Cisc and Risc constituencies. Others are already emerging in the horizon. For them to succeed, however, they will have to go through the constituency-building process of establishing themselves as the trends for the future: just like Risc is doing now!

5. Conclusions

This paper has examined the potential of the sociotechnical constituencies approach to integrate the treatment of "micro"/"macro" issues. It has shown how it could be used to gain a better understanding of the process of establishment of techno-economic trends and *de facto* standards. The case of the microprocessor industry has been extremely fruitful. In particular, it has proved easily amenable to a "constituencies" characterisation from product to industry. We have seen how at product level some of these constituencies are direct competitors (e.g. SPARC versus MIPS), while at the architectural level they are members of the same broader constituency (e.g. Risc), sharing common goals and competing against other broader constituencies (e.g. Cisc) for control of the overall development of the industry. In this process, exogenous and endogenous factors have continuously transformed into each other and, to an important extent, they have become indistinguishable analytically. I think the assertion has been validated that technical and market trends are not really exogenous to constituencies: sociotechnical constituencies themselves create and alter them according to the extent of their relative strengths, dynamism and growth. On the other hand, it is true that once these trends gather momentum, they are likely to appear to many social constituents as an external force, a technology-shaping environment influencing the products of the constituency. The experience of Risc, in particular, has revealed how emerging product-constituencies do implement pro-active trend-creating strategies in order to establish themselves as industrial trends. By so doing, they simultaneously re-define the existing content of the "macro" industrial level. In contrast, Cisc was originally a case of "micro"/"macro" identity, with the product-constituencies actually creating the industry. Today, the shaping force of Cisc's established trends is still very strong, underpinning a Cisc-dominated "macro" industrial constituency, which Cisc companies are clearly striving to reproduce.

This integrated "micro"/"macro" approach contrasts strongly with the simplified world assumed in models which explicitly or implicitly deal with technology at a single level of analysis. For instance, Katz and Shapiro's discussion on firms' compatibility strategies explicitly assumes a two-product/firm situation in which competitive advantages are revealed and built up in the course of two periods. In this simplified situation, they argue that, in the presence of network externalities, compatibility leads to reduced competition during the first period [38]. Conversely, competition would increase with incompatibility. This may be correct at the proposed simplified level of analysis, but the present study on microprocessors has revealed a much richer situation in which compatibility at one level is clearly related to strong competition at a broader level. We have seen, for instance, how, at the level of product-constituencies, the firms MIPS and SPARC are stimulating compatibility among all their licensees in order to enhance competitiveness at the broader level of Risc architectural constituency. In turn, the Risc architectural constituency as a whole is trying compatibility with Cisc (accumulated software), not to decrease competition but, precisely, to break the oligopolistic control of the market at present exercised by the Cisc constituency.

Another example highlighting the relevance of the integrated "micro"/"macro" approach is provided by Teece (63), who pointed out that in the microprocessor industry the design issue was relatively straightforward: deliver greater power and speed while meeting standards of existing software base. At the same time, entirely new families of microprocessors could emerge which will define a new industry and software standard. In these instances, Teece argued, basic design parameters are less well defined, and can be permitted to "float" until market acceptance is apparent. The findings of this paper show a much more inter-active and pro-active picture than the one suggested by Teece. There is competition between established designs (Cisc product-constituencies); competition between emerging designs (Risc product-constituencies); and, simultaneously, competition between established and emerging designs (Risc/Cisc architectural constituencies). As a result, not only are Risc and Cisc shaping each other with Cisc evolving into Crisp and Risc trying to access the software base of Cisc. Also, leading Risc companies are far from simply "floating" their designs for market acceptance; they are implementing aggressive constituency-building activities aimed at establishing these designs as industrial trends.

Clearly, the current world of microprocessors is not a simple one. My view, however, is that "micro"/"macro" constituencies have helped us to gain some rich insights into this world and, particularly, into the understanding of the processes currently shaping its major industrial trends. Some of these insights have already been pointed out, but there are others which point to issues of general validity such as the important role of the nature and maturity of the technology in conditioning the limits and opportunities for constituency-building. In this respect, I think the study has lent support to the idea (proposed in the section on sociotechnical constituencies) that technology is conditioned by the opportunities and constraints imposed by the physical world and its own nature and state of the art at any given time.

Thus, microprocessor technology has been revealed as an architectural, codified-knowledge component with indirect network externalities and weak appropriability regime. Furthermore, Cisc is the established, whereas Risc is the emerging, microprocessor technology. The study has shown how each one of these characteristics has played a role in the strategies pursued by leading Risc and Cisc constituents. For instance, the "architectural technology" nature of microprocessors enabled Intel to implement an initial licensing strategy in order to promote the build up of the 80 × 86 constituency, but discard it at the next compatible chip in an effort to monopolise the benefits of a strong constituency now in place. In turn, the codified-knowledge nature of the technology, and consequent weak appropriability regime, has enabled AMD and others to copy or emulate the 80 × 86 architecture, thus leading to the legal disputes which now characterise the evolution of the more mature Cisc constituency. In contrast, the leading players of the emerging Risc technology are openly licensing their architectures – benefiting from the pool of disaffected semiconductor companies created by Intel's and Motorola's decision not to license – in an effort to speed up the build up of their own constituencies. Risc is also responding to the strength of Cisc's network externalities by devising strategies to access the huge base of accumulated software, which is largely responsible for Cisc's control of the industry. The study has also shown Risc responding better to the requirements implied in the component nature of the technology. In particular, by following open systems, Risc is showing greater responsiveness to long-term trends, specially, in the critical computer systems market. We have argued that trends in critical systems markets should be treated as part of the "macro" industrial level of microprocessors, precisely because of the component nature of the technology. Risc is doing it better than Cisc, which seems to be counting on the protection provided by software network externalities. Finally, the analysis has also shown that, although Risc's perceived inherent advantage in terms of cost/performance is likely to prevail in the long term, the relentless advances in semiconductor technology (transistor budget) are at present enabling the Cisc constituency to put up a hard battle to maintain its dominant position in the overall microprocessor constituency. In hardware, the evolution of the entire microprocessor constituency is being shaped by the continuous prevalence of Moore's Law.

The Cisc versus Risc experience has also highlighted the potential risks of both fragmentation and complete proprietary control in technological processes involving strongly competitive situations. Specifically, the Risc constituency-building process has suffered from an excessive fragmentation in its use of the Unix operating system. Different constituents have mostly chosen incompatible versions of Unix with the result that a market fragmentation has tended to develop within the constituency. This has on the one hand counteracted the promises of open systems gains and, on the other, delayed software developers from making the crucial investments needed for rapid build up of the critical base of software constituents. A major policy issue for the Risc constituency is therefore how to accelerate the generation of a common Unix standard which would enable effective portability among the Unix-based application software written for the different Risc platforms. Fragmentation is not a problem at present affecting the Cisc constituency. In fact the study has shown that the potential risks for Cisc come precisely from the opposite direction, that is, from leading Cisc companies' seemingly excessive zeal for monopolistic control of the technology. Thus, we have seen how Intel is striving to gain total control of the huge 80 × 86 PC market with a view to reaping monopoly profits. As Risc gather momentum, however, there are already signs that some important systems companies are moving towards the Risc constituency not just because they do not want to miss out on Risc but also in disapproval of Intel's sole-sourcing policy. Ironically, in trying to retain complete control, the dominant Cisc constituents may be actually helping to bring about the last thing Cisc would want to see, namely, an acceleration of the Risc constituency-building process. For Cisc, therefore, an important issue of policy is to find ways of striking a balance between a short-term policy of architectural control which enables premium profit margins and the long-term need of effectively reproducing the allegiance of its huge number of user-constituents. Looking back, the experiences of fragmentation and proprietary control of both Cisc and Risc clearly support and, indeed, may well benefit from the following statement made in section 2. The balance between collaborative or competitive interaction will fundamentally affect the evolution and dynamism of the resulting sociotechnical constituency. The success or failure of the sociotechnical constituency depends largely on the ability of the constituents to strike a balance between their individual interests and the development of the constituency as a whole.

Last but not least, the constituencies analysis of the microprocessor industry has highlighted the complexity of the processes of constituency-building for a technology emerging in a field where a powerful and far-from-exhausted constituency tends to occupy almost every segment of the market. A brief excursion into this process, from a Risc versus Cisc point of view, suggests that during the initial period new companies, completely embracing the new technology, are most likely to lead the charge of the emerging constituency particularly against the companies where the established constituency has been most successful. In other words, the main battles tend to be predominantly inter-institutional although the emerging constituency may already be taking shape within the institutional bastions of the established constituency too. We have seen, for instance, how the aggressiveness of Sun and MIPS in pursuing the build up of the Risc constituency has been in stark contrast to the difficulties experienced by the Intel and Motorola Risc constituencies which are growing under the shadow of the dominant Cisc constituency. Later, if and when the emerging constituency gathers a stronger momentum, the competition for resources is likely to expand from a predominantly inter-institutional struggle to an intra-institutional struggle as well. In particular, the competition for the creation, production and diffusion resources within the institutional bastions of the older constituency is likely to get stronger and stronger. This is an issue of policy which Intel and Motorola are now confronting and which is likely to give the companies a great deal of trouble if Cisc begin to show more definite signs of waning. Thus far, the Risc versus Cisc process is not at all decided. In fact, as normally happens, the established constituency is seeking to respond to the challenge of the new one (Rosenberg's "sailing-ship" syndrome) and this is a struggle that may last for years with no assured or complete victory for the new emerging constituency. For instance, many of the institutions of the older constituency may simply decide to become members of both constituencies simultaneously, very much as even Intel and Motorola are themselves doing. This seems to be the predominant movement at present and the microprocessor industry has yet to see a total shift of many Cisc constituents into the emerging Risc constituency. Indeed, it may well be the case that both constituencies will keep growing side by side for a long time in a competition which will shape the dynamism of the overall microprocessor constituency. On the other hand, if the Cisc versus Risc process eventually leads to a complete shift and mass migration of Cisc institutional constituents into the Risc constituency, then a process of simultaneous momentum-gathering and momentum-losing would have become firmly established. At this stage, the demise of the Cisc constituency would only be a matter of time, and the leadership of the companies which grew with Cisc would inevitably dissipate, unless they successfully manage to become leaders of the new constituency too.

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