Techno-economic networks and irreversibility

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Abstract

This paper explores the heterogeneous processes of social and technical change, and in particular the dynamics of techno-economic networks. It starts by considering the way in which actors and intermediaries are constituted and define one another within such networks in the course of translation. It then explores, first the way in which parts of such heterogeneous networks converge to create unified spaces linking incommensurable elements, and second how some of these links achieve longevity and tend to shape future processes of translation.

Introduction

Science and technology lie at the heart of social asymmetry. Thus technology both creates systems which close off other options and generates novel, unpredictable and indeed previously unthinkable, options. The game of technology is never finished, and its ramifications are endless. But how should we think of technological change? How should we think of the relationship between science, technology, and asymmetry? And how, in particular, should we make sense of the processes that build up and break down asymmetries?

During the last ten years sociologists and economists have shown that the standard models of technological development are flawed. Technology rarely grows in a predictable and unilinear manner within a relatively stable social and industrial context (Foray 1989). Models which assume this cannot explain its radical, and sometimes revolutionary, character. Instead, the new sociology and economics of technology suggest that science and technology are a product of interaction between a large number of diverse actors. But how should we describe and analyse these interactions?

As yet there is no satisfactory answer to this question. Here, however, I want to explore it by introducing the concept of the techno-economic network (TEN). This is a term which I will use to describe a coordinated set of heterogeneous actors which interact more or less successfully to develop, produce, distribute and diffuse methods for generating goods and services. It is sometimes possible to predict the way in which a TEN will evolve. The unilinear model of technological change is not always wrong. But more often the actors have significant degrees of freedom. They develop complicated strategies and many possible innovations with unexpected social and technical implications. The question, then, is how and why this happens. How should we make sense of the radical potential of technology, of its relationship to social and economic asymmetry?

In Part 1 I describe a set of analytical tools for exploring the mechanisms by which heterogeneous activities are brought into relationship with one another, and introduce the concepts of intermediaries, actors and translation. In Part 2 I show how networks are established and evolve, and talk of convergence (which deals with the construction of a unified space for incommensurable elements) and irreversibilisation (which has to do with the longevity of these connections and the extent to which they are predetermined). I also touch on network dynamics and consider the way in which both agency and the possibility of quantification depend on the character of the network. Finally, in the Conclusion I argue that the relationship between the macro- and the micro-social and many of the great social and technical asymmetries reflect network punctualisation.

1. Actors and intermediaries

Life is complicated. But I will start with a heuristic simplification and assume that TENs are organised around three distinct poles: First there is a scientific pole which produces certified knowledge. This is where scientific research is practised: for instance, in independent research centres, universities and relatively basic industrial laboratories.

Second there is a technical pole which conceives of, develops and/or transforms artefacts. Its products include models, pilot projects, prototypes, tests and trials, patents, norms, and technical rules,
and it is found in industrial technical laboratories, research associations, and pilot plants.

Third there is a market pole which refers to users or consumers who more or less explicitly generate, express or seek to satisfy demands or needs. In one sense these poles are worlds apart. What does a research scientist working on the fine structure of ceramics have in common with a consumer looking for a powerful but comfortable, economical and reliable car? In principle they are as different as chalk and cheese. In practice, however, they are linked. The scientist who worries what her colleagues think about her work, the engineer trying to convert a prototype into a pilot product without giving away proprietary information, and the consumer — in one way or another these are all connected. But how are they connected? How do they interact? How do science or technology interact with the social? How do they shape one another? To understand this we have to draw both on economics and on sociology.

Economics tells us that it is things that draw actors into relationship with one another. For instance, it tells us that a consumer and a producer enter into relationship via a product. Or that an employer and an employee are linked because the skills of the latter are mobilised and paid for by the former. Economists thus speak of intermediaries. And this is an important insight that may be generalised. I will say, then, that an intermediary is anything passing between actors which defines the relationship between them. Examples of intermediaries include scientific articles, computer software, disciplined human bodies, technical artefacts, instruments, contracts and money.

Unlike economics, sociology does not start with a stylized image of the actor. Instead it assumes that actors are only intelligible when they are inserted into a common space which they have built themselves. For instance, Crozier and Friedberg (1977) speak of actors and systems, Bourdieu (1980) of agents and fields, and Parsons (1977) of roles and functional prerequisites. In their different ways sociologists thus assume that every actor contains a hidden but already social being: that agency cannot be dissociated from the relationships between actors.

Economists teach us that interaction involves the circulation of intermediaries. Sociologists teach us that actors can only be defined in terms of their relationships. But these are two parts of the same puzzle, and if we fit them together we find the solution.

This is that actors define one another in interaction — in the intermediaries that they put into circulation.

1.1 Intermediaries

Again I will simplify, and talk of four main types of intermediary: First there are texts, or more generally literary inscriptions (Latour 1986). These include reports, books, articles, patents and notes. These are materials, for they are inscribed and circulate on paper, floppy discs and magnetic tapes — relatively immutable media that resist transport. Second there are technical artefacts. These, which include scientific instruments, machines, robots and consumer goods, are (relatively) stable and structured groups of non-human entities which together perform certain tasks. Third and obviously, there are human beings, and the skills, the knowledge and the know-how that they incorporate. And fourth there is money in all its different forms.

I want now to argue that such intermediaries describe their networks in the literary sense of the term. And they compose them by giving them form. Intermediaries thus both order and form the medium of the networks they describe.

Texts as networks

Texts are vital to many areas of social life, but nowhere more so than in science (Callon et al. 1986; Latour 1989). Thus a scientific text may be seen as an object which makes connections with other texts and literary inscriptions. The choice of journal, of language and of title — these are the methods by which an article seeks to define and build an interested audience. The list of authors tells of collaboration and of the relative importance of each contribution. Here, then, is the start of a network. But that network extends into the references and citations. These rework the cited texts, insert them into new relationships, and identify and link new actors together. Words, ideas, concepts and the phrases that organise them thus describe a whole population of human and non-human entities. Some may be well established and others novel. But taken together they define, explore, stabilise, and test their identities against one another. A text may speak of electrons,
enzymes, government agencies, oxides, methods, experimental arrangements, multinational companies and sectors of industry. But like the actors in some American novels who would otherwise never come together, their destinies are intertwined in the 'socio-technical dramas' described in scientific papers.9

The words in a text refer to other texts, and rework and extend the networks to be found in these. So whereas, traditionally, we have assumed that texts are closed — we have distinguished between their context and their content — now we are saying that texts have neither an inside nor an outside. Rather they are objects that define the skills, actions and relations of heterogeneous entities. Thus, like other texts, the scientific article is a network whose description it creates.10

Technical objects as networks

What is the strange alchemy that allows us to transmute groups of non-humans into networks that define and link heterogeneous actors? How can we treat machine tools, internal combustion engines, video recorders, nuclear plants or automatic ticket machines in this way? Recent work in the sociology of technology, in particular by Madeleine Akrich and Bruno Latour, suggests that a technical object may be treated as a program of action co-ordinating a network of roles. These roles are played by non-humans (the machine itself and such other objects as accessories and power supplies) and 'peripheral' humans (such as salespersons, consumers, repair people).

In practice it is not too difficult to describe the programs embodied in technical objects, or the ways in which their socio-technical components act, communicate, issue orders, interrupt one another and follow protocols. The reason is that descriptions or 'textualisations' are common. Technical objects are not as dumb as we think!

Thus in its design stage, the character of an object is endlessly debated:11 what will it look like? what will it do? what will it be used for? what skills will its users need? what maintenance will it require? Such talk is heterogeneous. Indeed engineers transform themselves into sociologists, moralists or political scientists at precisely those moments when they are most caught up in technical questions. Should a car be treated simply as a basic and economical means of transport? Or should it satisfy repressed desires for conspicuous consumption (Callon 1987)? Should users be allowed to intervene when a solar lighting kit breaks down? Or should it be hermetically sealed to stop damage by amateurs (Akrich et al. 1987)? Answers to these questions — questions about design — are both technical and social. They imply decisions about the definition and distribution of roles between the object and its environment. The definition of an object is also the definition of its socio-technical context: together they add up to a possible network configuration. There is no 'inside' or 'outside'.

Such 'textualisation' is also found in apprenticeship. Here the instructor describes the operation of an object: the network 'scribed' in it is set out and inspected. What are the links between technical objects? And what are the roles that humans play? Perhaps they watch a sluicegate and press a lever? Or observe the screen and click the mouse? In this way the machine is interpreted, deconstructed, and inserted back into its context — though possibly not in the way intended by the designer. The written traces of such efforts to put objects into words are to be found everywhere, as are the controversies to which they lead.12

Codes, checklists, maintenance manuals and user handbooks, all of these escort objects on their travels (Akrich 1989b), and sometimes texts are inscribed in the machines themselves. Such texts impute skills to humans — the ability to detect different coloured signals, or to read labels which say 'on/off', 'record', or 'play'. Here machines are ordering human beings around by playing with their bodies, their feelings or their moral reflexes (Latour 1988).13

To sum up, artefacts are not the enigmatic and remote objects to which they are often reduced. When they come into contact with their users, they are carried on a wave of texts which bear testimony to the scars of the textualizations that accompanied their design and displacement (Akrich 1989a). Technical objects thus more or less explicitly define and distribute roles to humans and non-humans. Like texts they link entities together into networks in ways that may be decoded.

Skills as networks

Embodied skills may also be treated as networks of entities. Sometimes, to be sure, humans may be seen as networks of 'purely social' flesh and blood: perhaps this is the picture of humanity
carried by head-hunters. More often, however, they are thought to embody technical skills. Thus a ‘pure’ technician such as a computer programmer or a disciplined production worker induces groups of non-humans to play their roles. Other skills operate within a ‘pure’ universe of codified texts (bureaucrats or accountants) or financial instruments. The division between context and content disappears again. No description of skills is possible unless the networks of humans, texts and machines within which they are expressed and put to work are reconstituted (Cambrosio and Limoges 1990; Mustar 1989). To describe a skill is thus, at the same time, to describe its context.

Money as a network

Traditionally, money is interpreted as a reserve of value and instrument of exchange. As an instrument of exchange, it demands something in return and a minimal but essential return in the form of information. Accordingly, it constitutes the buyer and seller and measures the strength of their mutual commitment – a relationship explored and analysed in economics. But the relationship between money and return is even clearer for reserve value, or public or private funding (Aglietta and Orlean 1982). For instance, when venture capital funds research, this is based on a program of action, which acts as counterweight to the loan. In this money is textualised, translated into orders, indicators and recommendations. These define and link a range of heterogeneous human and non-human actors: cooperate with X at ICI and Y from Laboratory Z to obtain a critical temperature of 150°K and you will get a loan of $. A. Here again the intermediary is a network of roles.

From pure to hybrid intermediaries

These are limiting cases. In practice, the world is filled with hybrid intermediaries. Nowhere is this more true than for the texts which chaperone other classes of intermediary. Here we find that we are entering a civilization of inscriptions which covers all forms of intermediary. And the ubiquity of texts means that the equivalence between networks and intermediaries is strengthened. It is made more legitimate, more explicit, and more subject to challenge. The more one reads the more one links, and the more important it is to negotiate and compromise.

But human/non-human hybrids are no less invasive. Indeed, as several of the other contributors to this volume suggest, it is increasingly difficult to distinguish between humans and non-humans. For instance, there are systems of distributed intelligence which mix up computers that demand programmers and programers who mobilise computers with an abandon that would make Rene Girard tremble. Who is negotiating with whom? What implies what? Which is the actor, and which the follower? These are open questions.

Impurity, then, is the rule. Nowhere is this more visible than in the service sector. The product sold by Club Med, Cap Sogeti or CISI is a mixture of humans and non-humans, texts, and financial products that have been put together in a precisely co-ordinated sequence. Consider what it takes for Mr Smith to be able (and willing) to spend his holiday on the banks of Lake Rangiuaro, watching the barracudas mingle with the tanned bodies of his fellow-humans. Computers, alloys, jet engines, research departments, market studies, advertisements, welcoming hostesses, natives who have suppressed their desire for independence and learned to smile as they carry luggage, bank loans and currency exchanges – all of these and many more have been aligned. Truly the intermediary linking Mr Smith to the (initially improbable) dreams and interests of the package tour operator is monstrous and complicated. But in principle it works like any other intermediary. If Mr Martin uses a fork to mash potatoes this is just another (albeit simpler) intermediary. Like its more complex cousin it assigns him a role – the role of human being with a number of options and rights. So what lies at the end of the chain is equally easy to describe in both cases. The complexity of the intermediary itself is irrelevant.

Decoding intermediaries

I have tried to show that intermediaries more or less explicitly and consensually describe their networks. That is, they describe a collection of human and non-human, individual and collective entities. These are defined by their roles, their identities, and their program – which all depend on the relationships into which they enter. My argument has two consequences. The first has to do with
the crucial role played by intermediaries in giving shape, existence and consistency to social links. I want to say that actors define one another by means of the intermediaries which they put into circulation. The second is methodological. It is that the social can be read in the inscriptions that mark the intermediaries.

At the time of the Renaissance the great Book of Nature was read and re-read. Now we must extend the literary metaphor. Our concern should be to read the many intermediaries that pass through our hands: to learn to read artefacts, texts, disciplined bodies, and cold money. Sociology is simply an extension of the science of inscriptions. Now it should broaden its scope to include not only actors but the intermediaries through which they speak.

1.2 Actors

In the way I initially want to define the term, an ‘actor’ is any entity able to associate texts, humans, non-humans and money. Accordingly, it is any entity that more or less successfully defines and builds a world filled by other entities with histories, identities, and interrelationships of their own. This initial definition suggests that intermediaries are synonymous with actors. For instance, a scientific text seeks to create a reader with the skills needed to mobilise, consolidate, or transform the network described in the paper. Thus it acts: it is an actor. And the same is also true for other intermediaries. Like intermediaries, actors may be hybrid. They may but need not be collectivities. They may take the form of companies, associations between humans, and associations between non-humans. In this ontology actors have both variable content and variable geometry.

Of course, actors are not always successful. An article may not find the right readers, or it may be deconstructed. A machine may rust away. An incorporated skill may find no employer. An application for a grant may be turned down. And so on. The injunctions to act are inscribed in intermediaries. If nothing is said or inscribed (and I have argued that inert matter is talkative) then nothing acts. Action works via the circulation of intermediaries. These tirelessly carry messages which describe (in both senses of the word) the networks in which they are inscribed. Why then, do we need the notion of actor? Why should we not simply make do with that of intermediary?

The answer has to do with authorship. All interactions involve a method for imputing intermediaries to authors. Indeed, authorship is often inscribed in the intermediaries themselves. Scientific articles are signed and technical objects are trademarked. Incorporated skills are attributed to the body or to the subject. Thus I want to say that an actor is an intermediary that puts other intermediaries into circulation — that an actor is an author. And, to be sure, that the imputation of authorship, like all the other claims or suggestions made by intermediaries, is controversial, open to doubt or question.

Defined in this way, an actor is an entity that takes the last generation of intermediaries and transforms (combines, mixes, concatenates, degrades, computes, anticipates) these to create the next generation. Scientists transform texts, experimental apparatus and grants into new texts. Companies combine machines and embodied skills into goods and consumers. In general then, actors are those who conceive, elaborate, circulate, emit, or pension off intermediaries, and the division between actors and intermediaries is a purely practical matter. Is a group an actor or an intermediary? Is an actor a force for conservation or for transformation? The answer has nothing to do with metaphysics, ontology, or the rights of ‘man’. Rather it is empirical.

Consider, for instance, the case of a nuclear power station. This is a hybrid, a monstrous group which regulates interaction between graphite rods, turbines, atoms, operators, control boards, flashing lights, concrete slabs and engineers. Should we refuse this group the right to be an actor? ‘It’ transforms everything that is fed to it. Files, bills, fuel, water, skills and budget lines are converted into electrons transported to consumers, taxes paid to local councils, and waste products — which in turn lead to the formation of groups of angry environmentalists. It is certainly a network. But is it an actor, given that it is just a black box that converts known inputs into programmed outputs?

The question is empirical. Is the plant the author of the intermediaries that it puts into circulation? And the answer is yes but only sometimes. Thus the plant is often seen as a simple link in a chain which extends from the user to the generating company, and perhaps beyond to the terrible nucelocrats who conceived and planned it. In this case the actors are taken to pass through the plant without stopping. And the humans who actually work there, like the turbines, isotopes, waste pumps and cooling circuits with which they interact, disappear into its deepest recesses. On the other hand, for certain purposes the plant is carefully distinguished
from everything beyond it and becomes an author. For instance, some doubt its reliability and safety, or the ability of the operators to maintain the necessarily level of concentration.

Here, then, is the ambiguity. Some treat the group as an intermediary aligned by other actors who lie behind it and put it into circulation. Others treat it as a dignified actor that may introduce unexpected and unprogrammed sequences and associations. This ambiguity is the stuff of controversy though its intensity depends, of course, on circumstances. When the clouds from Chernobyl spread over Europe to contaminate Lapp reindeer and Welsh sheep, the plant became an actor rather than an intermediary. Forms of talk treating technology as an uncontrolled and autonomous force — as an actor in its own right (Ellul 1964: Winner 1977, 1986) — gained ground over those treating it as an instrument or tool. Thus quite minimal changes may transform intermediaries into actors, or actors back into intermediaries. It is a question of where the buck stops. Either you focus on the group itself, and go on further, in which case you have an actor. Or you pass through it into the networks that lie beyond, and you have a simple intermediary.25

2. Networks

All groups, actors and intermediaries describe a network: they identify and define other groups, actors, and intermediaries, together with the relationships that bring these together. When such descriptions include an imputation of authorship, then actors emerge in the stopping places, asymmetries, or folds (Deleuze 1989). But the network of intermediaries accepted by an actor after negotiation and transformation is in turn transformed by that actor. It is converted into a scenario, carrying the signature of its author, looking for actors ready to play its roles. For this reason I speak of actor-networks: for an actor is also a network.

But how do different actor-networks, which have no a priori reason to be compatible with one another, ever manage to reach agreement? What happens if one does not accept another’s definition? Or if two actor-networks disagree about the nature of a third? How is it that sometimes agreements are reached? And those agreements may turn out to be durable? The answer to these questions has to do with convergence and irreversibility. But before discussing these I will first consider the elementary relationship between actors in the process of translation.26

2.1 Translation

‘A translates B’. To say this is to say that A defines B. It does not matter whether B is human or non-human, a collectivity or an individual. Neither does it say anything about B’s status as an actor. B might be endowed with interests, projects, desires, strategies, reflexes, or afterthoughts. The decision is A’s — though this does not mean that A has total freedom. For how A acts depends on past translations. These may influence what follows to the point of determining them. The methodological point is that the observer should not exercise censorship. S/he should collect all the translations. None should be rejected a priori. There should be no division between those that are reasonable and those that are taken to be fantastic or unrealistic. All the entities and all the relationships between these entities should be described — for together they make up the translator.

The notion of translation thus implies definition. But, definitions are inscribed in intermediaries (we are not toying, here, with idealism or psychologism), which come in many forms. Accordingly, it makes little sense to speak of translation ‘in general’. We have to define the medium, the material into which it is inscribed: roundtable discussions, public declarations, texts, technical objects, embodied skills, currencies — the possibilities are endless. Nevertheless the elementary operation of translation is triangular: it involves a translator, something that is translated, and a medium in which that translation is inscribed.27

Translations may change as time passes. Sometimes they are a product of compromise and mutual adjustment negotiated through a series of iterations (Akrich, Callon and Latour 1987). And when they are embodied in texts, machines, bodily skills and the rest, the latter become their support, their more or less faithful executive. At one extreme the latter may be an isolated and homogeneous intermediary. And at the other it may be a hybrid cascade of intermediaries with articulated roles, links and feedback loops between the actors. In either case, a concurrence with translation focuses on the process of mutual definition and inscription. And, to be sure, it extends the traditional definition of action.
2.2 The network

The nature of the relationship between actors and their networks is never finally resolved. Thus when two translations link together they generate a third which may bring together groups that would otherwise have been separate. But the observer does not need to adopt the position of one of the actor-networks, for networks are formed out of the aggregation and composition of all the relevant but more or less compatible actor-networks. And behind the heterogeneity we will find textualisations that are sometimes in agreement. Sometimes it is possible to make links – and it is in this process that we must seek commensurability rather than in the cognitive capacities of actors.

2.2.1 Convergence

Having spoken of translation I can now explore the dynamics of networks – the complex processes in which actors and their talkative (sometimes discreet) intermediaries weave themselves together. To do this I will talk of convergence and irreversibility. Convergence measures the extent to which the process of translation and its circulation of intermediaries leads to agreement. At the same time, it is a method for exploring the boundaries of a TEN. Convergence has two dimensions: alignment and co-ordination.

Alignment

In the elementary operation of translation two objects are defined by an intermediary. But the extent to which that definition is embraced and performed varies. Sometimes there is controversy, conflict, and the translation is rejected as betrayal: traditore-traditore. We find workers who do not want to play the role defined for them by the machine; consumers who doubt the quality and value of a product; scientists who denounce the arguments of their fellow-authors; borrowers who reject the conditions attached to a loan; or electrons that refuse to pass from one electrode to another. And we find actors who deny or reinterpret the character of their authorship: 'I only spoke about the memory of water in order to excite your curiosity. I was not really serious.'

Disagreements vary in scope. They may focus on an actor, or on an intermediary. They may lead to open controversy, or simply to abstention. And they may or may not be overcome. But a translation that is generally accepted tends to shed its history. It becomes self-evident, a matter on which everyone can agree. There is empathy, the perfect piece of information which circulates without difficulty with the unshakeable felicity described by Austin. And between these two extremes lie all those situations so well described in game theory in which each player puts itself in the place of the other and they work through a series of iterations to a possibly stable conclusion. A successful process of translation thus generates a shared space, equivalence and commensurability. It aligns. But an unsuccessful translation means that the players are no longer able to communicate. Through a process of disalignment they reconfigure themselves in separate spaces with no common measure. Translations thus both flow through and are held in place by intermediaries.28

When there is 'perfect translation', A and B speak in exactly the same way about themselves, about one another, and about the intermediary that links them together. There is total equivalence with no ambiguity. But the further one moves from such agreement, the greater the differences and incoherences. Isotropy gives way to a space full of discontinuities: we move from harmony to polyphony, and finally to cacophony.

A network starts to form as soon as three actors are joined together by intermediaries. There are two basic possible configurations:

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A ----> B ----> C
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The first is one of complementarity in which the relationships are transitive. If A translates B which translates C, then A also translates C. The second is one of substitutability in which C is similarly translated by A and B. The level of alignment depends on the success of the translations – and in the case of substitutability on the extent to which they resemble one another.
The same two configurations join together to form longer chains of translations, for however complex they may be, networks are built out of these two basic building blocks. So however complex and extended a network may be, we may determine how well aligned it is, albeit perhaps only qualitatively. A strongly aligned network is one in which the translations are successful and (in the case of substitutability) relatively similar. Conversely, a weakly aligned network is one in which these conditions are not fulfilled.

Co-ordination

The imputation of the authorship is an important part of the process of translation. But such imputations are shaped by more or less explicit and stable rules or conventions that have been produced in past interaction. What do these look like?

First, there are rules about the identity of actors. Is A really an actor? Here the issue has to do with the intermediaries that may be imputed to A. The rules that determine these questions range from written laws to customs. For instance, there are legal rules about attributing products to companies; there is legislation which can deny inventors the right to ownership of their invention, and there are unwritten conventions which prevent someone funding a research program co-signing the articles that emerge from it.

Second, and rather similarly, there are rules and conventions about imputing intermediaries to particular actors. Some of these are complex, controversial, and enforced only with difficulty. For instance, there are companies operating as civil persons, using commercial trademarks, which have neither the right to own property, nor the contractual ability to demand that the retailer pass on payments from the client. Here the ambiguities are huge (Eymard-Duvernay 1989). Again, a scientist may sign an article, but unless the signatures are in the right order, the date on which the paper was received by the journal is recorded, and there is some obligation to cite it, authorship of the translation inscribed in the paper may not be imputed to her at all.

Third, there are conventions about who may speak on behalf of whom. This is particularly obvious in politics, with its legitimated procedures for designating representatives — and also in industry where there are contractual and collective agreements which spell out responsibilities and working conditions. But such rules may also be found in the organisation of the market, where it takes the form of price controls, methods for regulating the prices charged by state monopolies, and informal networks which pass on information about reputations (Karpik 1989). Again, they are to be found in science: the ability of a scientist to ‘translate’ a higher order primate or a human being depends on a series of regulations — codes of ethics about permissible experiments.

All such conventions tend to rarely the universe of possible actors by organising imputation and limiting the number of translations that can be easily stabilised. I will call these codifying regulations forms of co-ordination or translation regimes. Some are intended to apply generally. Such conventions embody general definitions — for instance about what is to count as a citizen, an official diploma, a guaranteed loan, a standard technical object, or the conditions under which a loan may be made. On the other hand, some are limited in scope. These draw on more general conventions, but work to divide the universe of actors and intermediaries up into subsets with conventions that are locally, but only locally, valid.

Though the distinction is abstract, it makes good empirical sense. Thus there are many regulations which have only limited scope. These include: the constitution of cartels; collective agreements in specific industrial sectors; rules of professional certification; technical norms local to a few producers and users; the development of an appellation contrôlée for wines; the founding of consumer groups; the organisation of professional associations or scientific societies; the mounting of training courses for a few companies; and the creation of research associations. Such forms of local co-ordination often rest on more general regulations — for instance anti-trust laws. But the distinction between local and general conventions is only relative. General conventions may become local again if they are successfully denounced and challenged (Reynaud 1989). Conversely, local forms of co-ordination may be spread. Thus conventions from one sector may spread over the whole economy, private norms may become public, or conditions for guaranteeing credit may be generally adopted. Accordingly, I will speak of weak co-ordination when I wish to characterise a network which has no specifically local rules. And, conversely, I will speak of strong co-ordination to refer to a network shaped by both local and general rules. By comparison with the former, in the latter the universe of possible translations is relatively restricted, and network behaviour is relatively predictable.
Convergence

I will use the notion of convergence to refer to a combination of alignment and co-ordination. Thus the higher the degree of alignment and co-ordination of a network, the more its actors work together, and the less their very status as actors is in doubt. This does not mean that everyone does the same thing, for networks usually include a range of complementary actors – for instance scientists, technologists, entrepreneurs, salespersons and customers. Rather it points to the way in which the activities of actors fit together despite their heterogeneity. It also points to the way in which each actor in a convergent network is able to identify and mobilise the skills within that network without having to get involved in costly adaptation, translation or decoding. Thus in a convergent network, faced with an angry client, the salesperson immediately knows which engineer to call and how to describe the problem so that the engineer can work on it. Again the salesperson knows how to approach a basic scientist with an appropriately reformulated version of the problem. And the return journey is equally easy: usable recommendations and suggestions flow from the laboratory back to the salesperson.39

A totally convergent network would thus be a kind of Tower of Babel. Everyone would speak their own language, but everyone else would understand them. Each would have specific skills, but everyone else would know how to use them. It would be particularly efficient, for it would draw on both the force of the collective and the synthetic capacity of the individual. Each actor would be able to speak for all, and to mobilise all the skills and alliances in the network. And the network as a whole would be capable of concentrating its efforts at a single point. But such a network is a limiting case. Strongly convergent networks only develop after long periods of investment, intense effort, and coordination.30 There are many others which are only weakly convergent – networks in which actors find both that their status is constantly in question, and that it is difficult (albeit not impossible) to mobilise other parts of the network.

2.2.2 Boundaries

The boundary of a network can be related to its level of convergence. Thus I want to suggest that an element may be treated as lying outside a network if it weakens the alignment and coordination – that is the convergence – of the latter: when moved into the network. This, however, raises a further question: that of measurement. How can one calculate a degree of convergence? How can one give it a numerical value? How can one trace the boundary between inside and outside in practice?

These questions depend on the methods for identifying and describing translations or intermediaries. Since any intermediary can be put into words or texts, in effect they have to do with how to analyse the more or less redundant body of texts which define actors, their identities, and their relationships. In practice the appropriate method of measurement is extremely straightforward (though it is also computationally demanding). It is a simple matter of counting the number of times in which a specific translation is inscribed in the relevant body of texts or textualisations.

Another important element in the establishment of boundaries concerns the compatibility of translation regimes. This is just one of the dimensions of convergence. For instance there are rules and regulations which distinguish the scientific pole and render it partially autonomous from – but at the same time link it in specific ways to – the technical. These include: delay in the publication of results which derive from research funded by industry; the principle of the non-appropriability of published results; and regulations about the patentability of certain organisms produced by genetic engineering.

Finally, it is possible to distinguish between long and short networks. Long networks include all the poles and intermediaries described above: they extend from basic academic research into ‘science-based’ industrial sectors. Short networks do not reach so far. Though they may draw on industrial research from time to time, such links are neither stable nor systematic. Short networks are thus organised around the technical and the market poles. The distinction thus concerns the length of the detour that has to be organised in order to create or to develop a market – though both, of course, have to do with the co-ordination of activity.

2.2.3 Irreversibilisation

I will say that the degree of irreversibility of a translation depends on two things:
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(a) the extent to which it is subsequently impossible to go back to a point where that translation was only one amongst others; and

(b) the extent to which it shapes and determines subsequent translations.

Defined in this way the irreversibility of a translation is a relational matter—one which can only be measured when it is put to the test. It is also a matter that is never finally resolved: all translations, however apparently secure, are in principle reversible.

How can a translation resist persistent and obstinate assaults by competing translations? How can it see such challenges off? The answer depends on its durability and its robustness. Again, these are relational properties. As a number of other contributors to this volume show, it is easy to imagine that there is a gradient of material resistance stretching from inscriptions embedded in idle canteen talk, through laws and legal codes, to those that are etched into the concrete of a nuclear plant. Again, it is also easy to imagine that robustness might depend on the extent to which the identities of the actors inscribed in the translation are themselves resistant to erosion. But this is simply to displace the problem. Thus, as we have seen, actors are hybrid groups, constantly threatened by dissension and internal crises. So we must be careful, for no strategy is assured of victory. Overall, however, it could be said that irreversibility increases to the extent that each element, intermediary and translator is inscribed in a bundle of interrelationships. In such tightly coupled networks, any attempt to modify one element by redefining it leads to a general process of retranslation. Accordingly, I venture the following proposition: the more numerous and heterogeneous the interrelationships the greater the degree of network co-ordination and the greater the probability of successful resistance to alternative translations.

The durability and robustness of a translation tells us nothing about the extent to which it is likely to shape future translations. To what extent does a robust scientific text which withstands attack and translates a monoclonal antibody lead inevitably to specific research developments and necessary industrial strategies? To what extent do a microcomputer and its software, with their hierarchy of problems and roles for users, actually render the behaviour of the latter predictable? We might say that a translation is irreversible if it is likely to lead to a search for substitutes, or for translations that are intended to prolong its life or extend its scope. Apprenticeship is a case in point. In this the elements involved in a translation become dependent on one another in a process of mutual adaptation. A skilled machinist cannot work without his machine. The development of a technology depends on engineers with a specialist training. The practice of this trade puts specific objects into circulation. And so on. In this way decisions become more and more dependent on past translations.

The creation of systemic effects and the apprenticeship process are expressions of a more fundamental mechanism: that of the *normalisation* which accompanies and measures the irreversibilisation of translation. As David (1987) notes, this process is found in all kinds of hybrid groups. Normalisation makes a series of links predictable, limits fluctuations, aligns actors and intermediaries, and cuts down the number of translations and the amount of information put into circulation. It operates by standardising interfaces—that is, by standardising and constraining actors and intermediaries. Thus it may range from reference standards to fully compatible interfaces, by way of the definition of maximum and minimum thresholds. And if a relationship between actors is normalised, it may contribute powerfully to the production of systemic effects. This is because its elements are only able to rearrange themselves by making use of well-defined elements which adopt compatible standards. The stricter the compatibility rules (plugs) the more alternative translations are disqualified and the more predictable choices become. A network whose interfaces have all been standardised transforms its actors into docile agents and its intermediaries into stimuli which automatically evoke certain kinds of responses. The rules of co-ordination then become constraining norms which create and control deviance: the past engages the future. In a word, irreversibilisation, taken as the predetermined of translation and as the impossibility of a return to competing translations, is synonymous with normalisation.

With normalisation or standardisation comes the possibility of quantification. Minimal, norms for interfaces require at least one pertinent variable which may take one of two possible values—for instance, good or bad, or pass or fail. But they can extend to fine-tuning between multiple continuous variables by way of upper and lower threshold limits. The more precise and quantified these standards, the more a successful translation becomes irreversible. A network which irreversibilises itself is a network that has become heavy with norms. And it is a network that has slipped into a codified metrology and information system.
It is not hard to mathematise the description of such a network, since each element is quantitatively linked, by its specifications, to other elements. For example, it is possible to link the performance of a technical object (the speed, memory and power of a microprocessor), the type of user, and the price that they are willing to pay. With the irremissibility of translation and its normalisation we enter a world familiar to economists (Akrich 1989c). In effect it becomes possible to say that it would be expensive to challenge certain translations. This means that in order to establish other links and new translations you would first need to undo all those already in existence by mobilising and enrolling new alliances. Accordingly, I want to say that economics does not begin with the allocation of scarce resources, but rather with their localisation or ‘location’ (renting).

2.2.4 Network dynamics and punctualisation

Networks can rarely be cut up into simple and easily quantifiable descriptive frameworks. ’Putting things into numbers’, which is the extreme case of ‘putting things into words’ is only one possible form of description. Whether or not this is possible clearly depends on the state of the network. It makes no sense to try to quantify or to reduce behaviour to variables and functions under all circumstances. On the other hand, it is silly to reject all quantification. The choice of method obeys no epistemological imperative, since it is entirely dictated by the state of the network. If the network standardises itself then one is bound to count and calculate. If it is divergent and reversible, then excessive simplification (and quantification) will betray the state of the network, and it is better just to tell a story! Each actor is relatively unpredictable, because any translation is constantly being undone. Here, then, the only faithful — indeed intelligible — method is that of literary description. Such description multiplies points of view to form a polyphonic narrative distributed over as many voices as there are actors, and recovers all the relevant details.

When a network is strongly convergent and irreversibilised, it can be assimilated to a black box whose behaviour is known and predicted independently of its context. It may then link itself to one or more ‘external’ actor-networks with which it exchanges intermediaries. Under such circumstances it is punctualised in these other networks (Callon 1987). Complete industrial sectors, scientific disciplines, markets or technologies may be punctualised. Thus for certain purposes the microcomputer industry may be treated as a black box which produces a particular product with well-defined characteristics from specified inputs. It may be analysed by looking at the intermediaries which circulate between it and its neighbours.

The process of punctualisation thus converts an entire network into a single point or node in another network. But this may be repeated indefinitely. Punctualised nodes may be juxtaposed with other punctualised nodes in successive translations that are no different in principle from those discussed above. They may play the role of actors or intermediaries. The principle, then, is general: networks of punctualised networks may themselves be folded up into points. And, as such points are clustered together, so one moves from the micro-social to the macro-social. But convergence and irreversibility may also decrease. Indeed, they may decline catastrophically. Sometimes markets collapse, industrial sectors are dislocated, and scientific specialties tear themselves apart. The macro-social is no different in kind from the micro-social, and we may chart the rise and fall of asymmetry by exploring the fate of these punctualisations.

Conclusion

TEA are not like networks as normally defined. They bear only a distant resemblance to the technical networks (such as telecommunication systems, railways or sewers) studied by economists. These can, in essence, be reduced to long associations of non-humans that, here and there, join a few humans together. Nor are they reducible to the networks of actors described by sociologists, which privilege interactions between humans in the absence of any material support. Techno-economic networks are composite. They mix humans and non-humans, inscriptions of all sorts, and money in all its forms. Their dynamics can only be understood if we study the translation operations which inscribe the mutual definition of the actors in the intermediaries put into circulation and ‘read’ the relevant inscriptions. Further, the translation operation is itself regulated by more or less local and revisable conventions.

One of the advantages of reasoning in terms of TEs is that it shows that actors’ own theories are not universal. The behaviour of actors, and more generally their definition, changes with the
state of the network, which is itself the product of previous actions. The actors and their profiles of action may be characterised for each possible configuration of a network. The less convergent a network, the less it is irreversibilised and the more the actors composing it can be understood in terms of concepts such as strategy, the negotiation and variation of aims, revisable projects, and changing coalitions. Under such circumstances analysis has to start with the actors and chart their fluctuating interactions. The trail is still hot. Information is scarce, contradictory, asymmetrical, and difficult to interpret and use. Uncertainty rules the day.

At the other extreme, in completely convergent and irreversibised networks, the actors become agents with precise objectives and instruments for establishing hierarchies, calculating costs and measuring returns. The trail is cold, and the story is economised. The states of the world — that is to say, the states of the network — are known for each point at each instant. Information as delivered by the translation inscribed in the intermediaries is perfect (the network is known and predictable) but limited (it does not go beyond the network under consideration). Controversy and disinterestment (to use the language of translation sociology) is highly unlikely. The paradox is that the actors have no choice, since they are ‘acted’ by the network that holds them in place. Conversely, they are only in a position to act deliberately when there is imperfect and asymmetrical information.

There are many intermediate situations between those two extremes — such as, for example, procedural rationality, or mutual anticipation of game theory (Thévenot 1989). This line of analysis deserves development. If it proves to be well founded then it opens up an entirely new space in the social sciences. It suggests that there is no theory or model of the actor, even in the plural. The actor has a variable geometry and is indissociable from the networks that define it and that it, along with others, helps to define. So it is that history becomes a necessary part of analysis.

Some will say that I have offered a method for describing TENs and their asymmetries, but not a theoretical framework for their explanation. But the opposition between description and explanation is in large part undermined by the method I have proposed. The more convergent and less reversible a network, the more the descriptions delivered by the intermediaries turn into explanations or predictions. Talk of explanation assumes that network evolution can be described using a small number of variables or concepts. But this requires a very strong assumption about the shape of the network and the convergence of its translations. In a strongly convergent and irreversibilised network, the actors are perfectly identifiable, and their behaviour is known and predictable. The whole works and evolves in a regular manner as a function of a few simple laws and some well chosen information. In a divergent and reversible network the description has to cover all the details, since every detail counts. This is because each actor endeavours to translate the others and these translations fluctuate without ever stabilising. But anyone who looks for explanations under such circumstances will learn nothing about the mechanisms by which irreversibility is created. Thus those who oppose qualitative or strategic analysis to the search for laws and regularities overlook the way in which networks are not in the actors, but are produced by them. And they ignore the way in which networks only stabilise at certain places and at certain times.

Notes

1 For work showing this, see Gille 1978; Hughes 1983; Perris 1988; Katz and Shapiro 1985; Arthur 1989.
4 For a characterization of the morphology of TENs, see Callon et al. 1990.
5 Obviously many, perhaps most, activities lie between these three poles and are somewhat similar to the compromises between natures described by Boltanski and Thévenot (1987). See also Law’s discussion of interdiscursivity (this volume).
6 As I will argue below, the distinction between intermediaries and actors has to be treated with care.
7 This solution for linking sociology and economics differs from the notion of ‘embeddedness’ revived by Granovetter (1985). The networks he describes are pure associations between human beings.
8 On immutability which is central to action at a distance, see Latour 1989.
9 Like The Sentimental Education, a scientific article thus tells a story that takes the reader by the hand and more or less successfully moves him or her: ‘But, truth to tell, he did not go very far that morning, since almost on top of the battery, where his student Li Guo had left it the day before, lay a freshly photocopied five page article from the pages of Zeitschrift fur Physik. Chu could barely contain his excitement when he read the title: “Possible High Tc Superconductivity in the Be-La-Cu-O System” ‘ (Hazen 1989: 24).
10 The equivalence of texts and the networks they describe has been meticulously established in the sociology of science. Note that texts include diagrams, laboratory notes, patents, user manuals, catalogues and market surveys (for analysis of patents, see Bowker 1989.) Note also that scientific texts are increasingly important in economic life. Indeed, much economic activity might be described as the conversion of scientific texts into marketable goods! (Atlee 1987, Law 1992).
11 See, for instance, Callon 1981; Latour and Coutouzis 1989; Ackrie 1987; Law 1992.)
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The list of possible intermediaries, combinations, actions, and coincidences is endless.

23 The economics of conventions, which has gone so far to undermine the standard model of economies, stops short when confronted with the actor: 'The authors of this issue agree that the role played by common conventions should not lead to an abandonment of the principles of methodological individualism. Only people can be actors, whether or not these are taken as members of a group or an institution.'

(Dupuy 1989).

24 The fact that human bodies are a class of intermediary does not mean that they are not also actors!

25 This definition leaves a number of thorny questions unresolved, and in particular the distinction between humans and non-humans that has obsessed and continues to obsess the so-called human sciences. A good example — here taking the form of fear of the big bad wolf — can be found in Bourdieu, who writes: 'It suffices to think what would happen if, in the fable, dogs, foxes and wolves were allowed their own say in the classification of canines'. (Bourdieu 1982).

26 As a number of contributors to this volume imply, the habitual distinctions between human and non-human and living and non-living cannot account for the division between actors and intermediaries. Human beings are often 'reduced' to the status of intermediaries, just as non-humans are elevated to the dignity of actors (as when rights are accorded to legal entities and inanimate objects). In principle all configurations are possible, though conventions and legal rules reduce the legitimacy of some imputations.


28 Machines, human bodies, and texts, in their role as intermediaries, lie at the root of misunderstanding, disagreement, and (re)conciliation. The telephonic creates a common space that integrates as much as Durkheim's religion, or Bourdieu's habitus. And nuclear plants generate conflicts just as intense as those to do with the rights of 'man'.

29 They are not just a simplification device.

30 In the market pole, users are aligned if they all seek a standard product (substitutability) or their choices are mechanically linked to those of others (complementarity). The first represents the conditions assumed in neo-classical orthodoxy, and the second is close to those described in the sociology of consumption or the economics of network externalities. But to analyse market structures as defined in economics (the link between supply and demand) we have to add the technical pole to that of the market, and explore their hybrids. This creates additional configurations, some but only some of which are explored in economics.

31 These may be assigned to the company for which they work.

32 The operation, and to some extent the development and interpretation of these rules, depends on groups that Antoine Henion calls mediators which work to focus attention on certain targets. They may be human (lawyers, notaries, barristers, industrial property owners), texts, or technical objects. For instance concert halls direct the attention of the audience to the singer and scientific journals print the names of the authors in bold. Mediators lie half-way between actors and intermediaries. They do not simply 'pass on' or 'transmit', for they also intervene. On the other hand, imputation does not stop with them. Mediators orchestrate the recognition that separates an actor from the crowd.


33 The notion of translation regime is somewhat like the 'natures' described by Michel Callon


12 Equally, there is 'textualization' when objects generate controversies — that is explicit but contradictory network structures. Rival descriptions and accusations are a chaotic mixture of the technical and social: there are just as many contradictory interpretations of a controversial nuclear plant as there are of Baudrillard's Le Fleurs du Mal. Technical objects are no more nor less transparent or opaque than literature. And if the nineteenth century was the age of literary criticism, then the twenty-first century will be the age of 'technology criticism' in which we decode and comment on the networks brought together in artefacts.

13 Examples include: the alarm clock which rings, stops with a verbal command, and then starts again and rings until the button is pressed; the chains which prevent the machinist from letting go of the grinder; the dead-man's handle in a locomotive; the TV image which evokes a gesture of solidarity.

14 Semiotically, we might say that there is a return to the emitter from the recipient.

15 A play on words in the original between 'liv (read) and 'lie' (links). Translator's note.

16 Note that the impure service sector is becoming more important to the economy as a whole.

17 Furthermore, the production of 'material' objects and 'non-material' services may be described in the same terms.

18 This is related to the concept of speech act (Austin 1970) and text act (Coleman 1988). There are many examples of texts which consistently give rise to acts: a signed cheque leads to a transfer from one account to another; a signature at the foot of a notarised document opens the doors of a flat to a new occupant; an instruction typed on the keyboard of a computer starts a printer.

19 It is very rare to find groups of humans with no non-humans. A non-human almost always inserts itself between two bodies. But even an unmediated interaction between two bodies — a pure association of humans — which in reality only occurs in the act of sex (and then often in the presence of condoms which take the little factor/intermediary of the AIDS virus into consideration) can give rise to contradictory imputations. Is the other person simply a vessel for base instincts, with no conscience? Is she just a faithful intermediary for his or her genes? Or should one of the partners have control to the other, and so transform the act into a message of love? Who can answer this difficult question definitively? Who can say where the actor is?

20 The intermediaries discussed here include texts, technical objects, bodies or money. But a general network theory would include all possible intermediaries, ranging from the free association of the analyst's couch, through whispered confession and repentance, to the accusations of an Azande sorcerer. All are intermediaries, all bases for communication, and all organise networks and link their component parts. The old woman who repeats the same list of sins for the nth time to a tired priest contributes to a world peopled with humans and non-humans. There are priests who pardon, Gods, saints and angels, who love, punish or redeem, there is Satan who tempts, and there are neighbours who consent to be the object of good or bad actions.

21 Imagine that the client on the analyst's couch or the penitent in the confessional is no longer thought to be the author of his or her actions. (This is perfectly plausible: psychoanalysis dissolves the person into a series of authors, and exorcism seeks to uncover the agency of Satan.) At this point, agency shifts. The client becomes a medium through which the unconscious expresses itself, a set of symptoms to be decoded. The penitent is robbed of free will, and possessed by the devil.
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alignments (notably users/clients) that preprogram the actors and make market studies possible in practice.

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