1 From Economic Foundations to S&T Policy Tools: a Comparative Analysis of the Dominant Paradigms

Laurent Bach and Mireille Matt

BETA, Strasbourg, E-mail: bach@cournot.u-strasbg.fr
BETA, Strasbourg, E-mail: matt@cournot.u-strasbg.fr

1.1 Introduction

The objective of this chapter is to analyze the economic rationale behind science and technology (S&T) policies. Reference will be made to concepts and ideas stemming from works in other fields, such as management sciences, sociology, etc. For the purpose of this analysis, we first identify the main theoretical frameworks on the basis of which innovation related phenomena are currently analysed in economic terms. Next, we identify for each framework, the justifications for State intervention as well as the main forms that this intervention might take.

In order to simplify the presentation and the very subtle, complex, and sometimes controversial scholarly debate (Lundvall and Borras 1997)[1], two main frameworks are distinguished: the neo-classical (NC) and the evolutionary-structuralist (ES), which adopt different approaches that highlight specific aspects. The following questions are addressed in relation to each framework:

- main features, especially regarding innovation;
- the "circumstances" in which the innovation processes do not work well or fulfil the role they are designed for, and the consequences of these so-called "failures";
- the principles of State intervention designed to remedy these failures, illustrated by the most representative types of S&T policy action that can be adopted. (Frameworks are heuristic tools rather than the basis for di-

[1] See also works by Metcalfe (1995, 1998), Metcalfe and Georghiou (1998) and Lipsey and Fraser (1998).

rectly operational policy advice; a detailed description of these is beyond the scope of this present work);

- the main problems raised by these principles when they are implemented into real actions; government failures are included here.

Broadly, it will be assumed that each framework provides rationales for science policy, technology policy, and also, more generally, for innovation policy (and even for other types of policy, e.g. competition policy, trade policy, education policy, and so on). In other words, the hypothesis is that within each framework, the rationales behind every policy are the same. For this reason (from an analytical point of view) we have not separated science policy from technology policy. However, the combinations of these different policies and the frontiers between them vary from one framework to another.

In Sections 1 and 2, we present the two frameworks and their implications for S&T policy. As most of the elements of this analysis are well documented in the literature, we focus only on the main aspects, or those aspects that are not always highlighted. Tables 1.1 to 1.2 summarize the analysis. Table 1.1 presents the main features of each framework; Figure 1.1 presents the types of "failures" connected with each. framework as well as the basic principles of S&T policy, central to each framework, that are designed to remedy such failures; Table 1.2 shows how the main types of S&T policy actions can be seen as specific applications of these principles. (The way this is presented allows comparison of the underlying principles on the basis of which real, although archetypal, policy actions are formulated.) Section 3 is devoted to one key point underlying the question of State intervention: the additionality problem. We conclude by offering some comments about the complementarity of the two frameworks and a comparison of the policy principles and policy actions resulting from each.

1.2 The NC Framework

1.2.1 Allocation of Resources, Technology as Information, and Market Failures

Of the two frameworks proposed, the NC is probably the one that exhibits the highest level of internal coherence, because of its inherent linear logic. This exists within its foundations and also in some measurement tools. For this reason, and probably also for historical reasons, it is the dominant framework, although it has been strongly challenged by the competing paradigm from the late 1980s. Without going into too much detail, the key

point in relation to innovation and technological progress is how they have been endogenized by the neo-classical approach (roughly since Arrow (1962)), whereas before they were treated as exogenous to the economic rationale (more precisely they were considered as "given", and their origin was not questioned; they were included in the choice parameters of agents or seen as equally influencing all of these agents). In line with the "input/output" neo-classic way of reasoning, innovative activity is performed by an individual agent (the innovator) using inputs to produce a particular good, i.e. the technology, which is regarded as information (see Table 1.1). The line of argument put forward on theoretical grounds by Arrow (1962) and Nelson (1959) is roughly as follows: the peculiar activity of innovation and the peculiar good resulting from it do not show the "adequate" properties that the theory requires to optimize the decision of the agent. Namely, there are some indivisibilities in both the inputs and the outputs; the output is uncertain and may take a long time to realize and, being a non-rival and non-excludable good, it is non-appropriable.

The consequence is the well-known "lack of incentive" to innovate on the part of the innovator. The activity is costly, mostly because of its indivisibility, and is risky, because of uncertainty, on the one hand as regards its final outcome, and on the other as regards the level of demand resulting from the problem of price determination (according to the so-called "paradox of information", the buyer does not know the value of the information unless he buys it). Moreover, the economic gains are difficult to appropriate since they may benefit: i) consumers or clients, who have access to better products without necessarily being charged a corresponding increased price; this is the basis of the consumer surplus and "market" externalities; ii) competitors and the rest of the economy could use the technology produced by the innovator without paying anything, giving rise to "knowledge" and "network" externalities (see, for instance, Griliches (1979) on market and knowledge externalities, and Jaffe (1996) for a clear exposition of the links between the three types of externalities). In other words, the private rate of return to the potential innovator is too low for him to make further investments, although the social rate of return for the rest of the economy may be high. In this situation, the resource allocation mechanisms that are at the heart of the neo-classical approach do not work so as to generate the socially optimal situation: the investment in innovative activity is inferior to its socially optimal level because of these "market failures".

1.2.2 S&T Policy Principles and Actions

To remedy this situation, the State can ground its S&T policy actions on some basic principles. For instance, the State can:

- try to provide (or help to circulate) better information to reduce uncertainty and to give the demand (supply) side better information on supply (demand);
- substitute wholly or partially for the market either on the supply side (by itself carrying out innovative activity, or contributing to the firm's investment in research and development (R&D) by means of subsidy, tax credits, grant, etc.), or on the demand side (by ordering innovative outputs – products, processes, techniques or whatever – to firms, or helping agents to buy such outputs), in order to reduce, or more evenly distribute, the uncertainty and the risk and to reduce the cost for innovative firms. By "substitute", we mean that public action takes over from the private action that would have been required in order to reach the social optimum. The basic assumption here is that the cost savings for firms will compensate for their losses from externalities; the amount invested by the State, therefore, should not be larger than the sum of the externalities;
- promote mechanisms or regulations to remove or diminish externalities or facilitate their internalization in the agent's optimizing calculations:
  - to provide a property right to the innovator on his technology as a compensation for generating knowledge externality (this rewarding role of patents being closely linked to their protection role, which is probably more important);
  - to promote cooperation between users and producers of technology (vertical cooperation) to share market externalities, and costs and diminish the uncertainty;
  - to promote cooperation between producers of technology (horizontal cooperation) to share knowledge externalities and share the costs and the risks associated with the production of technology.

Table 1.2 and Figure 1.1 set out these basic principles and include a list of the corresponding S&T policy actions.

According to the NC approach, these corrections to market failures will lead the optimizing rationality of agents to allocate resources through market mechanisms in such a way that a "second-best" equilibrium can be reached. The "first-best" equilibrium is not possible due to these market failures; but State intervention allows the system to achieve a "second-

best" equilibrium (inferior to the "first-best", but better than the situation would be without any public policy). If State intervention leads to such a "second-best" equilibrium, there is "additionality" compared to a situation in which there is no government action.

Obviously, this is an oversimplified picture, and since Arrow's seminal paper many new arguments have developed, which have made it more complex, although, from our perspective, they are all within the same general framework.

Perhaps one of the most important developments at the boundary of the NC paradigm is the so-called "new economics of science and technology" developed by, among others, Dasgupta, Stoneman, and David (Dasgupta and David 1994; Foray 1991). On the one hand, it helps to explain the implications of the public-good properties of technology considered as information, as well as the inherent and specific properties of information (for instance, in relation to its value, its cumulative and combinatory nature, the high costs of its production compared to the low costs of its duplication, the network externalities associated with it, etc.). These features contribute in a sense to reinforcing the NC conclusion mentioned earlier. On the other hand, the new economics of S&T proposes that a new line be drawn between science-related and technology-related activities, and their respective outputs. A tentative summary of the proposed distinction would be that it relies not so much on the nature of the outputs (both fundamentally subject to non-rivalry and at least partial non-excludability) than on:

- the practices of diffusion associated with incentive schemes (openness or free access to scientific results, with priority to the inventor associated with social rewards – this is largely inspired by Robert Merton; closedness or property rights on technology outputs associated with economic reward, i.e. appropriation of the economic gains from innovation through market mechanisms);
- the possibility to choose the optimal level of codification taking into account the reward system;
- the greater uncertainty in the production and use of scientific results;
- the results of basic research being considered mainly as an information input for applied research.

One fundamental outcome of these new developments is that they allow for a better justification of the distinction between S&T policies in the NC framework. To a certain extent, the justification for State intervention is stronger for science, especially if one includes the indivisibility of the production process (with its comparatively higher costs for science than for

technology) and the more generic usefulness of scientific outputs, thus allowing for larger externalities. In the field of science, State intervention is generally direct, through funding, while for technology it is indirect (accomplished through co-funding and the property rights system). In this respect, science policy is almost always acknowledged to be indispensable, even though some argue (probably too simplistically given the analysis developed above) that the type of results produced by publicly supported basic research are not useful for industry, because if they had been, the industry would have done the research itself (Kealy 1996). But both science and technology policies still rely on the same analytical grounds. More generally, following the linear model of innovation, education policy is aiming at providing the system with "good inputs" (researchers), and diffusion policy is aimed at helping agents to adopt innovation and circulating information about existing or potential needs and resources.

From another standpoint, the endogenization of technology in economic analysis has also been the ambition of macroeconomic analysis, in the field of endogenous growth theory or New Growth Theory (NGT). However, here also, despite various technical refinements, only some types of development, accumulation and diffusion of information have been introduced, guided by rather simple forms of appropriability regimes and incentives, and most frequently associated with other classical hypotheses related to behaviour and the search for equilibrium (see, for instance, Firth and Mellor (2000))[2]. It is questionable, therefore, whether these approaches have provided much more than an illustration at macro-level and a formalization of the innovation-related phenomena already identified, which, however, is obviously a very useful achievement. To move further along this line, it must also be acknowledged that learning phenomena are not completely absent from the neo-classical perspective, especially in NGT. Certain forms of "learning by doing" might, for instance, be compatible with this perspective.

However, NGT and the new economics of S&T are at the frontier of both frameworks, especially the latter approach, which, in many ways, avoids this fundamental feature of the NC paradigm, i.e. that, "... the closest we get to something called *learning* is *information acquisition*" (Lundvall and Borras 1997). More precisely, one of the main (or the most important) differences with the second framework resides in this point, as outlined below.

[2] This is not to say that specialists of NGT, such as Romer, ignored the tacit dimension of knowledge, but they did not fully incorporate this dimension into their models.

1.2.3 About Empirical Problems of Applications and "Government Failures"

Without entering into major debate about the relevance of the NC view and its compliance with reality, the main problems raised by the application of the principles of State intervention should be outlined.

The first problem is related to the difficulty involved in identifying the situations in which "market failures" occur, and even more so the difficulty of determining exactly how to correct these failures in practice: which firm to support, which project to finance, which information to diffuse, how far to extend the property rights, and so on. The NC framework, as such, does not provide the tools to directly express real phenomena using the limited number of variables that are required to operate the optimizing calculation.

The second problem is inherent in the method adopted to correct the market failures. A good example here is provided by the proposed solution to the lack of appropriability, namely the property rights system. While on the one hand, the information should be the innovator's property in order to urge the innovator to innovate, this, on the other hand, introduces asymmetries of information between actors when the information does not diffuse to all actors. The "pure neo-classical" axioms stipulate that all agents have the same information, and this specific feature leads the system to the social optimum. Any departure from this hypothesis entails at best that the achievable equilibrium is only "second-best". In other words, there is a trade-off between guaranteeing the property rights to the innovator and diffusing the technology throughout society, and the right balance is not easy to find. The patent system is one solution to this problem, but it generates a distortion in the price mechanisms to the detriment of consumers because of the monopoly position the patent secures to the innovator: this, in turn, leads to a non-optimal social surplus. Moreover, the patent system may induce a duplication of innovative efforts by firms competing to be the first and to receive protection. Over-investment could then result, or, conversely, under-investment could re-emerge if one firm dominates the "patent race". Neither result would be socially optimal.

The same argument, more or less, as for the subsidy principles can be put forward: subsidy causes asymmetry for the one that benefits, which runs fundamentally against the "pure neo-classical" axioms. The fact that, in theory, the amount of subsidy should not exceed the amount of externalities generated by the innovation only ensures that a "second-best" optimum can be reached. The same argument is relevant for the promotion of cooperation, which restricts the diffusion of information and economic

gains to a limited number of agents, and thus creates failures in the distribution of information.

The argument underlying these trade-offs is that solving one market failure always makes another emerge. Thus, it is the balance between the positive effects resulting from the correction of the first and the negative effects of the second that is crucial. There is sometimes a risk that corrective public actions create other market failures that are worse than the original ones, i.e. that the increase in social surplus obtained as a result of the corrective action is inferior to the decrease in social surplus induced by the created market failure[3]. When this occurs it is termed "government failure" or "policy failure".

Obviously there are certain remedies to overcome this problem, for instance, in the case of the patent system, limitation in time and scope of the patent protection, the obligation to concede licences, a buy-out of the patent by the State, or even the replacement of the patent system by an ex-post reward system. But, these solutions raise other market failures (see, for instance, a discussion of the reward/buy-out vs. patent systems in the light of the role of patents in firms' strategy (Penin 2003)). In any case, the balance between the positive and negative effects of State intervention is hard to assess, and thus often as much a matter for policy decision as an economic one[4].

Another possibility is that the benefit effects are less important than the cost of intervention, the latter including the cost of researching information about the presence of market failure and the evaluation of the actual and "corrected" situation. These are both typical cases of "government failures" associated with the NC framework.

It is not surprising that these two fundamental difficulties are related to the set of information owned by the State, and its capacity to acquire and use new information. For a "pure" NC theory, by definition there can be no such thing as government failure since the perfect information hypothesis holds. If one rejects this hypothesis, the consequences (in terms of strategies, incentives and modes of coordination of agents) of uncertainty, im-

[3] On the basis of this argument, other types of public policies may be required to limit the damage caused by technology progress on health or the environment.

[4] We should mention here the basic exceptions to competition policy accepted by public authorities:

- phenomena as exceptions to monopoly regulation: patents; financial support to the supply side in the case of high cost and natural monopoly caused by indivisibility and related economies of scale;
- agreement as an exception to cartel and agreement regulation: R&D cooperation (with the idea of "pre-competitive" cooperation fully coherent with the distinction between science and technology mentioned above).

perfect information and related asymmetries between agents should be investigated in depth (Laffont and Tirole 1993). This leads to a complexification of the different situations of market failure and allows for fine tuning of the applications of State policy actions listed above to specific contexts in terms of the information at the disposal of actors. If this is properly done, again, at least in theory, there is no possibility of further government failure.

Similarly, at the basis of another extension of the NC analysis, and particularly important for explaining the role of cooperation, is the question of the transaction costs associated with market relations (but not included in prices) and the influence of these costs on the determination of the optimal mode of coordination. But, again, most of the theoretic renewal in this field falls within the scope of the same framework, because it does not essentially preclude considering technology as information and favouring optimizing rationality. Therefore, we would be tempted to state that these approaches have not profoundly modified the NC framework.

However, it is arguable that the State has more information than the market, and, moreover, that it is more able than the market to adapt its information structure. To follow this line of argument, it should also be recalled that other developments in economic theory favour a more dynamic idea of competition, which would be seen as based on the continuous creation and exploitation of asymmetries, especially regarding information. As long as technology is treated as a set of information, and the choice of agents is seen as an optimization taking into account existing or anticipatable alternatives, these approaches still remain within the boundaries of the NC paradigm. Despite the progress of analytical tools and the continuous refinements to and complexification of contractual schemes in this field, there is still room for more dynamic approaches to take account of these asymmetries of information.

Another instance of "government failure" emphasized by some researchers in the field of public administration theory, is related to the process of decision-making in public bodies, reflecting private interests, lobbying, etc. and raising the unsolvable – at least using the NC analytical apparatus – problem of the aggregation of individual preferences.

1.3 The Evolutionary-Structuralist Framework

1.3.1 Creation of Resources, Knowledge and "Learning Failures"

Under this heading falls a constellation of approaches that have some strong common features. Three main approaches can be distinguished – very artificially and for pedagogical purposes: the evolutionary approach, the systemic approach, and the knowledge-based approach. Often inspired by other disciplines than economics (sociology, history, psychology, management, epistemology, biology, etc.), they claim to be part of the Schumpeterian heritage, and have for a long time been built against the NC framework. Over the last ten to twenty years, they have been developing and been being refined at a great rate, and have probably been gaining in coherence with the emergence of the knowledge-based approaches (although the full implications of these for S&T policy are still to be explored).

Again, it is beyond the scope of this study to specify the main features of this framework. It remains only to underline that most of them can be seen as being opposite to the features of the NC framework (see Table 1.1). What is probably more relevant here is that this framework fully acknowledges the learning capacity, or, more generally, the cognitive capacity of agents and groups of agents (individual as well as collective capacity). This does not only embrace a capacity to learn something that would exist somewhere, but also the capacity to create new knowledge, especially by changing ways of thinking, beliefs, visions, routines, etc. In terms of innovation, cognitive capacity concerns not only scientific and technical knowledge, but also the complementary knowledge required along the innovation process (organizational, management, etc). The key points are that on the one hand knowledge cannot be reduced to pieces of information, but is a mix of tacit and codified knowledge, while on the other, knowledge is intrinsically linked to the cognitive dimension[5]. This has some decisive consequences on appropriation and diffusion phenomena: for example, learning is obviously a cumulative and collective, rather than a purely individual process. This logically leads to an acknowledgement that it is a context-dependent process, which varies from one agent, group

[5] The economics of science and knowledge also recognizes this tacit dimension of knowledge, but without emphasizing the cognitive dimension associated with knowledge (see an analysis of problems raised by this point of view and of the related debate about the codification of knowledge in Ancori et al. (2000) and Cowan et al., (2000)).

of agents, firm, industry, clusters of industries, regions, institutions, etc. to another.

The three approaches that we consider to be at the basis of ES thinking (respectively the evolutionary, the systemic and the knowledge-based approaches), more or less explicitly possess all the features mentioned above. But each focuses on some specific aspects and, therefore, has brought some decisive concepts and analytical tools to the global framework. It is remarkable to note that these concepts, most often with quite minor adaptations, have been adopted by the other approaches, which use them as indispensable to their own conceptual construction.

In following the logic of our description of the NC framework, we are tempted to argue that the evolutionary, the systemic (including national or local systems of innovation, clusters, and the like) and the knowledge-based approaches have provided respectively the "general logic" of the evolution, the "how it works", and the "basic engine" of evolution. But the main problem lies in defining what would correspond to the NC optimal situation. Surely there is neither a static nor a dynamic equilibrium-like situation, which would have very little meaning, if any, in this learning-oriented framework. Correspondingly, there is nothing like optimality, even though it is sometimes possible to assess *ex post* if one situation is preferable to another. Referring to Schumpeter's cycle analysis reinterpreted and enriched, the only apparent consensus on this would be to assume that:

- the system follows some trajectory induced by a paradigm, and therefore it must be able to exploit a "good trajectory" as well as to ensure a "good transition" from one paradigm to the other;
- in order to be able to do so, in the whole system and at all levels of the system, there should be sufficient diversity to allow the selection processes to perform satisfactorily;
- this should be accomplished without too much loss of cohesion, which would unbalance the system and/or prevent it from evolving well;
- the basic engine that allows for all of this would be the maintenance of, or increase in, the cognitive capacity of all agents or groups of agents at all levels of the system.

With an approach in which all phenomena and processes are so complex and intrinsically related, it is rather difficult to identify and especially isolate "failures", as we did for the NC paradigm. Indeed, the term failure is adopted for the sake of simplicity, but may be misleading. In the "market-oriented" framework, as already stated, there is always an implicit or ex-

plicit reference to an "optimal situation" that would be reached if all theoretical conditions were fulfilled, that is, if markets and behaviours were perfectly similar to the prediction. It is through reference to this mythical "optimum" that something is seen as going wrong, as "failing". Within the alternative framework, this reference to an optimal situation does not exist and it is thus not exactly appropriate to consider "failures". One should rather consider "traps", "dysfunctions", "gaps", or "holes", leading to "dilemma and trade-offs" between existing forces driving the system, rather than "dilemma and trade-offs" between two possible states of the system (as choosing between two "second-best" situations). Various authors have already pointed to some of them (Malerba 1996; Smith 1996; Lundvall and Borras 1997; Metcalfe 1998; Teubal 1998), but there is no unified and unanimously accepted list of failures in the evolutionary constructivist framework.

We will assume here that what matters are, generally speaking, "learning failures", i.e. problems that limit (or constrain the use of) the cognitive capacity of agents and groups of agents. A series of failures falls within this type of failure; they are expressions of learning, and cognitive problems in different contexts and at different levels of analysis. We propose then to distinguish between:

- exploration/exploitation failures: misallocation of efforts and of cognitive attention to one activity to the detriment of another;
- selection failures: technology, practice, firms (infant firms, for instance) or other sorts of "species", among which selection is at work, are eliminated too rapidly (or maintained too long), or maintained based on inappropriate criteria;
- system failures: lack of coordination and complementarity between the cognitive activities of agents and groups of agents; rigidity of cooperative structures; lack of appropriate institutions allowing a collective creation and diffusion of knowledge; bad adjustment and desynchronization between the evolution of institutions and technological evolution;
- knowledge processing failures: codification problems (lack of standards and platforms, rigidity linked to excess of standardization, appropriability of codes, etc.); lack of/limitation of/absence of/control over absorptive and emitting capacity; lack of capability to articulate knowledge coming from different sources (for instance, external and internal to a firm); structure of knowledge badly adapted to appropriate sharing and distribution.

As suggested earlier, the negative consequences of these different types of failures (and thus basically resulting from a deficit of cognitive capacity) are principally lock-in to "bad trajectories", lack of diversity in the system, difficulty in creating new paradigms and in warranting a transition from the old to a new paradigm, and the existence of "gaps" in terms of knowledge, networks, institutions, economic and social conditions, and so on, all of which unbalance the evolution of the system.

1.3.2 S&T Policy Principles and Action

Based on the above, the basic principle of State policy should be to help, by all possible means, the development and the orientation of the cognitive capacity of actors and provide conditions conducive to the use of this capacity. The different approaches developed within the ES framework will put the emphasis on different aspects of this question. For instance, researchers investigating innovation systems will defend the role of institutions, infrastructures and collective interactions. The supporters of knowledge based economics will debate the necessity to help with the codification process or to support the development of a knowledge infrastructure allowing for a better use of the increasing amount of codified knowledge within the whole society. Therefore, these basic principles of State policy can be activated in very different ways, such as the promotion of norms, platforms, or other knowledge-related infrastructures, support to communities and agents of knowledge, reinforcement and adaptation of the education system, renewal of the property rights system to take account not only of the cumulative nature of knowledge creation, but also the nature of the knowledge and of its other modes of appropriation, support for infant firms at their different stages of development, etc. Above all, action must be adapted to contexts defined according to geographic, industrial, sectoral, market-related, and institutional dimensions. Table 1.2 and Figure 1.1 set out these basic principles and include a list of corresponding S&T policy actions. Table 1.2 shows only the main S&T policy actions, which can be combined, adapted, refined, etc., and thus promote a wide range of practical initiatives.

To close the loop, the adequate use of an appropriate cognitive capacity is then supposed to provide the conditions for appropriate selection processes, with sufficient diversity within which the selection mechanisms operate, and without too many "gaps" in the system. In turn, this would guarantee the evolution of the system along satisfactory trajectories and through relevant paradigms. This rather naïve picture could obviously be made more sophisticated by orienting it towards some specific aspects in-

volved in learning. But, fundamentally, it would be within this argument, even though this argument may appear somewhat simplistic.

In this framework, the frontiers between science policy, technology policy, and other innovation-related policy become blurred for various reasons. These include the fact that the actors are interacting at different levels within the system, the practices of diffusion, the incentives, and the fact that the activities of these actors are not strictly differentiated between science and technology, and the nature of the knowledge produced is not fundamentally different. Moreover, knowledge is created everywhere in the system, and thus there is not an absolutely clear functional separation between activities and between actors as regards creation of knowledge, transformation of knowledge into innovations, and diffusion. For instance, the clear-cut distinction between science and technology proposed by Paul David and others (see above) is called into question when analyzing the recent trends in the way research is performed in modern economies, as described in Gibbons et al. (1994). Therefore, coordination, coherence, and complementarity of policy actions are crucial in order to make the overall system better able to learn. For instance, recent work by Sherer (2001) shows that this is probably a combination of different policy tools that favours the re-dynamization of the US economy, especially as regards its innovative activity.

1.3.3 About Empirical Problems of Applications and "Government Failures"

Nevertheless, we still face a situation in which it is as easy to identify, in the real world, traces, examples, partial assessments, and finally pieces of evidence about the fundamental relevance of this approach (see the vast number of case studies, monographs and other empirical studies produced since the 1980s) as it is difficult to define metrics and tools to operationalize and measure all the concepts that have emerged over 20 to 30 years. The problem is complex and located at different levels: it concerns the "measurement" of some aspects, even in qualitative terms (for instance, diversity, learning capacity), the definition of what would be a good or satisfying level of the corresponding variable, and the desirability to reach some degree of homogeneity in the metrics, scales or analytical tools. With the complexity of the approach, due to its systemic and constructivist nature, this is probably the main problem encountered within this framework, mainly because it prevents analysts and policy makers from really envisaging the policy options that would favour the right balance between all the trade-offs.

A very important difference between both frameworks lies in the very "place" of the State. As underlined in Part 1.1.3, in the NC framework the State is normally considered as "outside" the market system. Therefore, if markets and behaviours are consistent with the theory then the State is needless. Only when market failures occur, does the State "appear". Then questions of public/private rate of return, crowding effects, substitution, and the like, arise and finally questions traditionally related to additionality. In the second framework, the perspective is quite different. The systemic, path-dependent, and cumulative approach fully accepts State-related institutions as being "part of the game" and recognizes their influence on institutional, technological, social, and economic changes. State-related institutions learn roughly according to the same basic rules as other actors. They do not necessarily have more knowledge, or greater cognitive capacity, or a broader vision, etc. than other parts of the system. Therefore, most of the "learning failures" listed above and which affect society, affect public bodies as well, and logically entail "government failures" (Malerba 1996). In this respect, the main source of "government failure" probably lies in the desynchronization of the speed of adaptation of public institutions and the speed of technological and scientific change in the system. This default in the speed of adjustment may have some negative countercyclical effects. Because of their specific role, public institutions are urged to develop integrative and coherent policy visions, tools and instruments, and to adapt constantly to the new requirements and trends in the economy. In this perspective, the "adaptive policy maker" should also continuously try to implement experimental policies, to use different policy instruments, to change the mix of instruments, and to make use of benchmarking approaches as policy learning mechanisms.

Policy learning should also encompass "diagnostic learning": it is also the ability to identify the changes in the environment and the changes in the relative position of actors (firms, countries, etc.) in this environment that is at stake. The recent debate about the "European innovation paradox" clearly shows the importance of this learning capacity upstream from the innovation policy itself (Muldur 2001).

1.4 The Issue of Additionality

1.4.1 General Remarks

The question of additionality is obviously at the heart of the justification for State intervention in the field of S&T, and, thus, is intrinsically linked with the rationale for S&T policy. But it is also linked with evaluation and

assessment problems. In this section, we try to focus on the first point, but inevitably there will be some links with evaluation that will be addressed.

Following Buisseret et al. (1998), the additionality problem could be expressed as: what difference does State intervention make? And this question should immediately be linked to a second one: does this difference justify State intervention?

Additionality then is directly linked to the consequences of policy action: but policy action aims at objectives that are defined according to the rationale behind each framework. This raises a double problem:

- difference could be assessed in the light of the targeted objectives, but other differences may occur that are beyond the scope of the targeted objectives, and may be unexpected;
- these unexpected differences can be coherent or not with the framework that gave birth to the objectives; if they are not, it will be necessary to adopt the theoretical view of the other framework to identify them and, if possible, to evaluate them.

An essential dimension of the additionality problem is related to the situation that must be seen as an alternative to State intervention. The temporal dimension is essential here. Two possibilities can be envisaged. The "null hypothesis" stipulates that everything would continue as before the public policy. The "counterfactual scenario" is a fictive construction about what would happen if there were no such State intervention (or, ex-post, what would have happened had there not been any policy implementation). Then *ex ante*, additionality is between the targeted situation (e.g. the objectives) and the forecast alternative scenario. *Ex post* additionality is between the actual situation and the alternative scenario, but this actual situation may be better or worse than the one the objective.

Directly linked to this question is at what level the alternative scenario is under consideration: project level, firm level, programme level, policy level, etc. As this alternative and hypothetical situation must be comparable with an evaluation of the actual or anticipated situation "with" State policy, both must logically be analyzed at the same level.

Another question relates to the temporal dimension: the time horizon over which the additonality is examined. "One-off differences" or short-term differences are one thing; probably what is more crucial is the persistence of these differences (decreasing or increasing) over time.

1.4.2 Different Concepts of Additionality

For a long time, debate ranged about how to analyze policy action as a means of providing inputs to the innovative process resulting (or not) in outputs from the process. This follows NC thinking about analysis of the activity of the agents, which is particularly appropriate when the policy action takes the form of providing input to the innovation process Within this perspective generally two types of additionality most often quoted are input additionality and output additionality. It is also necessary to concentrate on the process itself, introducing the concept of behavioural additionality. Finally, the recent development of knowledge-based economics (and its influence on the ES framework mentioned earlier) suggests that a fourth type of additionality might be envisaged, that is, cognitive capacity additionality. Each of these four types of additionality brings something to the global problem of additionality, but in isolation cannot address this global problem. Nor is the sum of the four types equal to global additionality. The four types of additionality are briefly defined and discussed in the light of the two frameworks proposed earlier.

1.4.2.1 Output Additionality

At first sight output additionality is the most intuitive: would we have obtained the same outputs without the policy action? Clearly this question is related to the problem of evaluation (i.e. the definition and measurement of the impact of S&T policy actions), which is beyond the scope of this chapter. However, some brief comments can be made.

First, again, the notion of output is strongly connected to the NC framework. Products, processes, and other physical devices, patents, articles, blue prints, and other forms of S&T products, can be more or less compatible with an output perspective (see the list of outputs adapted from the COMEVAL study, for instance, in (Bach and Georghiou 1998)). Knowledge, standards and norms could be considered as outputs, but with specific properties sometimes far removed from those of information-like outputs. But, cognitive capacity and all the various types of capacities that are rooted in it, do not fit into this frame.

Second, it is not possible to identify the "changes" brought about by the output; it is necessary to assess impact in terms of use (in production activities, through market relations, etc) of these outputs, to derive a global assessment of additionality from the existence of output additionality only. Thirdly, it is not necessary to do detailed analysis of the alternative scenario since the process involved is not so important. It is only necessary to

find a common definition and measure to compare the output obtained with what might have been obtained "if".

Finally, as suggested above, there might be cases where there is no additionality in terms of the outputs directly related to the objectives of a given policy action. However, there may be additionality derived from other types of outputs from this same policy action. This highlights the importance of choosing the relevant "array" of outputs that are considered in assessing additionality.

1.4.2.2 Input Additionality

The question here is: does public action add to the inputs dedicated by the agents to the innovative process or does it partially or completely displace these inputs? There are many arguments to explain why there could be displacement. The problem has been studied in depth in David et al. (2000), and extensively discussed from an ex-ante perspective. For instance, some academics have provided empirical hints (Jaffe 1996) and theoretical rules (Usher 1994), who employ an "incrementality test", to guide the choice of the appropriate public action (for instance, funding the right project). The overriding argument is that if the State financially supports actions that would have been conducted anyway by the agents, then these agents will be tempted to use their resources for other activities. Therefore, there is only additionality when the State supports actions that would not have been carried out by the agents (i.e. to which they would not have dedicated inputs), provided that the actions are socially desirable. In terms of the NC framework, this means that these actions result in a social rate of return higher than the private rate of return of the agent (this difference is often called the "spillover gap"), whereas the private rate of return from the same action without State support is inferior to the minimum required by the agent.

Since innovation is a risky activity, this ex-ante problem obviously is further complicated by the fact that the investment choice criteria become more like a trade-off between rate of return, and risk. Public funds could motivate an agent to carry out activities with high risk, but a high rate of return, leading to complementarity rather than displacement. Apart from the problem of uncertainty inherent in this type of investment, there is also the possibility that in some instances the State favours projects that are profitable from a private point of view, in order to demonstrate some kind of success from its policy.

But there could be other ways through which, at least, partial displacement may occur. The main example is the impact of State support for innovative activities on the supply of inputs to innovative activities; if it is

inelastic, then prices could increase and make the cost of these activities so high that the agents reduce their efforts in this field. The support given by the State to one agent could convince its competitors to reduce their own efforts because of the fear that they will be disadvantaged in the competition. State support may be seen as a revenue from, rather than an input to, innovation. Or the funds provided by the State may persuade other funders to reduce their requirements in terms of profitability; this is the sharing of risk argument.

It is often argued that the additionality problem is envisaged from this input perspective because there is a lack of available materials to elucidate the output additionality problem: the variables (basically the respective public and private resources invested in innovative activities) are more easily defined than those required to assess output additionality. We would rather say that it is only when we accept the relevance of the input/output type of analysis that this "proxy" analysis can apply.

It is quite clear that the application of input additionality as a parameter of public choice between the actions to be taken is closely linked to the neo-classical approach described earlier. In particular, it more or less explicitly involves the following assumptions:

- there is a clear link between input and output of the innovation activities;
- divisibility and constant return to scale of the innovative activity exist;
- the nature of the output generated by public funds and private funds is the same.

Naturally, advocates of the ES framework contest these views. On the one hand, they maintain that analysis of public financial support should always take into account how it is provided and the context in which it is used (beyond the structure of information asymmetries). On the other hand, they defend the complementarity of inputs rather than their substitutability related to crowding effects. Apart from the question of increasing returns or threshold effects in the production of innovative output, other arguments more deeply rooted in the ES framework are, for instance, that public funds could help to develop the knowledge base of the agents and their absorptive capacity, which could even allow them to reduce their own investment while increasing their profitability. Another line of argument is that thanks to the cumulative nature of knowledge creation, public support could increase the efficiency of future innovative activity by increasing the cognitive capacity of the firm. Therefore, input additionality has no general application in the alternative framework: we can say that some public money displaces, complements, or adds to private money, but it is only

when looking at the specific context in which public money is used that we can reach any conclusions about its additionality.

Note, that input is sometimes difficult to define in the case of policy actions that do not correspond to some sort of funding of innovative firms; obviously all policy actions are costly, so they always involve financial outlay on the part of the State, but it is not clear that this would be the best variable to take into account. Perhaps displacement/additivity of resources would be a more meaningful concept. For instance, in the case of property rights, comparing State investment in the legal system to the resources devoted by the agent to establishing some type of protection; in the case of cooperation, comparing State investment in the funding of networks with the resources invested by firms, etc.

1.4.2.3 Behaviour Additionality

The concept of behaviour(al) additionality relies on the possibility that State policy has an influence on the behaviour of agents: in the absence of public action, the agents might have acted differently during the time corresponding to the period of the policy action (for instance, during a State-supported project); the project could have been less ambitious, involved different partners, taken longer, etc.

One problem is that investigating the behaviour of agents does not directly give information about whether the behaviour "with" State action is better or worse than the behaviour "without" State action, i.e. if there is additionality or not. Also, to a certain extent, examining behaviour additionality seems redundant in the attempt to build the alternative scenario mentioned above, even though it might result in a much more detailed scenario than in the case of output additionality. From an analytical point of view, examining behaviour additionality only provides an explanation for the existence or the absence of input and output additionality. For instance, if one assumes that the objective of actions supported by the State would have been achieved (although perhaps later) and in a different way, even without State intervention, the difference looked for in the additionality analysis lies in the behaviour of the agents. In other words, by this means one could enrich the evaluation with an analysis of the innovation process itself, which could eventually help the policy maker to refine the way he implements his programme. To this extent, it does not add much to the solution of the additionality problem from either a neo-classical, or an evolutionary-structuralist perspective. However, it may allow us to compare different ways of reaching the same result, in particular different learning processes, if we adopt the second framework.

1.4.2.4 Towards a Cognitive Capacity Additionality?

As we have seen, the first two types of additionality (and to a lesser extent the third) are strongly connected with the NC framework and the related input/output method of analyzing the innovative activities. Based on the arguments developed in Section 2 of this chapter another focus might be the changes affecting the agents themselves, or, more generally, the changes affecting the system that runs the innovative activity. Following the different approaches to understanding organisations and systems, this could lead to the definition of organizational additionality, structural additionality, institutional additionality, behavioural additionality (in a quite different sense from that described above, dealing with the change in the agents' behaviour after State intervention[6]), etc. From an ES point of view, we would argue that the fundamental issue would be that of cognitive additionality. Does the policy action change the different dimensions of the cognitive capacity of the agent? It is obvious that cognitive capacity additionality is linked to those types detailed above. It depends on certain types of physical devices, on certain types of codebooks and codified knowledge (patents, publications, norms, etc.) and on certain types of explicit procedures (project management methods, quality control, etc.), that all to some extent could be considered to be outputs of the activity supported by the State. But whereas such outputs are treated as independent objects in output additionality, they are here context-dependent and combined with other dimensions of the cognitive capacity of the system affected by the policy action. Also, it can be argued that the changes in cognitive capacity will determine the future capacity to produce new outputs. But they cannot be reduced to some sort of discounted value of future outputs, since the cognitive capacity encompasses supplementary dimensions related to creativity and adaptation that allow determination of (adaptation to) future situations that cannot be envisaged.

It must be acknowledged that the difficulty of putting this concept into practice relates to the difficulty in defining all the dimensions of cognitive capacity and of the changes to it. Only some pieces of the puzzle can be identified. Some important dimensions could concern the absorptive capacity of the agent, its ability to master the codes used to articulate the existing and emerging knowledge, its capacity to interact with its environ-

[6] The agent will use different routines (project management, research activities, etc.) or will use existing ones differently; he will interact differently with his environment, etc.

ment, etc. Obviously, this is also related to the concepts developed by the competence-based approaches.

Finally, it is obvious that the problem of cognitive additionality in the alternative scenario is more complex than output additionality, and probably much too complex to cope with. The null hypothesis, although already very difficult to define, would be the only solution.

1.5 Conclusion: Beyond an Oversimplified Antagonism Between the Rationales for S&T Policy

The description in this chapter has painted a picture of a radical opposition between the NC and the ES frameworks. However, these frameworks should be envisaged in terms of their complementarity, each focusing on one particular aspect, that is, the problem of the allocation of resources (for the NC framework) and the problem of the creation of resources (for the ES framework). The fact that, according to the frameworks, one aspect is often privileged to the detriment of the other should not be seen as a problem. For instance, the NC framework can help us to understand how to solve incentive problems by enhancing resource allocation, but does not explain how this will result in scientific and technological progress nor how it will affect economic development. And, whereas the ES framework proffers some ideas about networking and the evolution of research and innovation systems, it does not help in determining the level of resources that should be allocated to the system and its components. This complementarity between the two frameworks is also clear when we look at the role of markets and the role that the State can play in terms of market creation. Although obviously central to the NC framework, the role of the market is not completely denied by the alternative framework, being acknowledged, for instance, to be a decisive element in the selection process. However, in the NC framework, the creation of markets requires the creation of demand or supply, the definition of property rights on the good that is exchanged, and the general conditions of market operation. In the ES framework the main focus is on the creation of an infrastructure and knowledge capacity, which are required to make the market exist. In other words, this framework tends to adopt a sociological view according to which the market is a social construct involving cognitive capacity, and not just a natural way of organizing the economy.

In terms of policy analysis and policy design, this complementarity first entails that market failures can coexist with learning failures, and probably these two aspects are more intrinsically connected than has been analyzed

so far (possibly one reinforcing the other). But a second, and equally important conclusion, is that the S&T policy actions derived from both analytical frameworks are neither necessarily different nor antagonistic, and may be also complementary. What is crucial is that a given policy action (for instance, subsidizing firms' R&D activities), seemingly common to both frameworks (although a much more detailed analysis would obviously reveal some differences in the practical applications of this given policy principle), is differently justified by each framework, and is effected for different purposes. For instance, property rights tools will be constructed with a view to optimizing incentives for potential innovators (in NC oriented policy), while they will probably be designed in order to help knowledge sharing and combination (in ES oriented policy). Similarly, cooperative R&D will be publicly supported to reduce risk and achieve cost sharing following a NC orientation, but will be supported to create or reinforce networking and the creation of collective knowledge in an ES perspective.

Much conceptual and empirical work remains to be done to thoroughly articulate the perspectives provided by both frameworks, and to benefit from a "dual use" of policy actions. Related to this question of duality is the question of complementarity and coherence between different policy actions. Facing different sorts of failures, the policy-maker is never able to choose one single action, but rather has to define a policy mix. This issue certainly needs deeper investigation.

Another consequence of this dual dimension of most, if not all, policy actions is that logically the impact of any one policy action should not be evaluated in the same way in each framework. In other words, as *S&T policy principles* are based on different rationales related to different theoretical frameworks (leading to different objectives), *evaluation techniques and tools* are based on different evaluation perspectives related to different theoretical frameworks (leading to different "objects" of evaluation). One must take account of this necessary coherence when launching any evaluation exercise. In this respect, the different, and surely complementary, dimensions of the additionality concept are particularly interesting, since they highlight how various rationales lead to various understandings of the possible "differences" generated by public intervention.

Since the mid-1980s, policy options have also been analyzed as favouring either the horizontal or, conversely, vertical dimensions. Again, in each framework, the alternatives could be justified, and one could not claim that a given option stems analytically from a particular framework. Neoclassical externalities could be higher between than within sectors, or market failures could be more prominent and damaging in certain sectors (Martin and Scott 2000), and the collective cognitive capacity could be

more or less relevant to different sectors. Another classification of S&T policy orientations is to distinguish between mission and diffusion-oriented policies (Ergas 1987). At first sight, mission-oriented policy appears to be more connected to the NC framework, while diffusion-oriented policy is more rooted in the evolutionary constructivist one. However, there may be circumstances in which the concentration of support for a small number of technologies, and for larger firms, is the best way to develop cognitive capacities and enlarge the knowledge base. Thus, the so-called large programmes that are frequently associated with mission-oriented policies can find justification within both frameworks. Conversely, diffusion of information and cooperation are not absent from the neo-classical perspective (Cantner and Pyka 2001). The two distinctions – horizontal vs. vertical policy and mission vs. diffusion policy – are a rather empirical orientation of policy, which always borrows implicitly or explicitly from both frameworks.

In both frameworks, there is also a need to combine S&T policy with other policies (anti-trust, commercial, education, etc.). In the NC framework, the distinction between the different policies is straightforward, since each of them can act on a limited and *a priori* defined set of variables of the NC model (such as incentives, price, market structure, etc.). In the ES framework, the differences are less evident and almost all policies can impact on the whole system because of all the interactions occurring at all stages. Recent works (Koelliker 2001) demonstrate the combined impact of S&T and anti-trust policies on innovation.

More broadly, it must be stressed that the present overview only deals with the theoretical basis of S&T policy. Obviously, actual policy-making is not a simple application of these theoretical recommendations, and is largely influenced by other rationales, for instance, related to politics, administration, lobbying, etc. A better knowledge of the coherence between those two sets of principles should certainly be developed in order to make the decision-making process more efficient and more beneficial for the whole of society.

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Appendix A

Table 1.1. The economic foundations of the two dominant paradigms

Standard/Neo-classical framework: main features	Evolutionist structuralist framework: main features
Market: unique mode of coordination and selection	State is part of the game
Equilibrium	No equilibrium
Static analysis	Dynamic analysis/Path dependency
Optimizing rationality	Other forms of rationality
Input-output perspective/linear model of innovation	Inter-active model of innovation
Central focus: optimal allocation of resources	Central focus: creation of resources, key resource is knowledge + knowledge is different from information
Normative reference: welfare/Pareto analysis	Unclear normative reference: "adequate" system/process/cognitive capacities? Environment ensuring
Research (S, T, I) as input-output system producing information + information as an input for downstream activities	Knowledge coming from anywhere in the system (not only research)

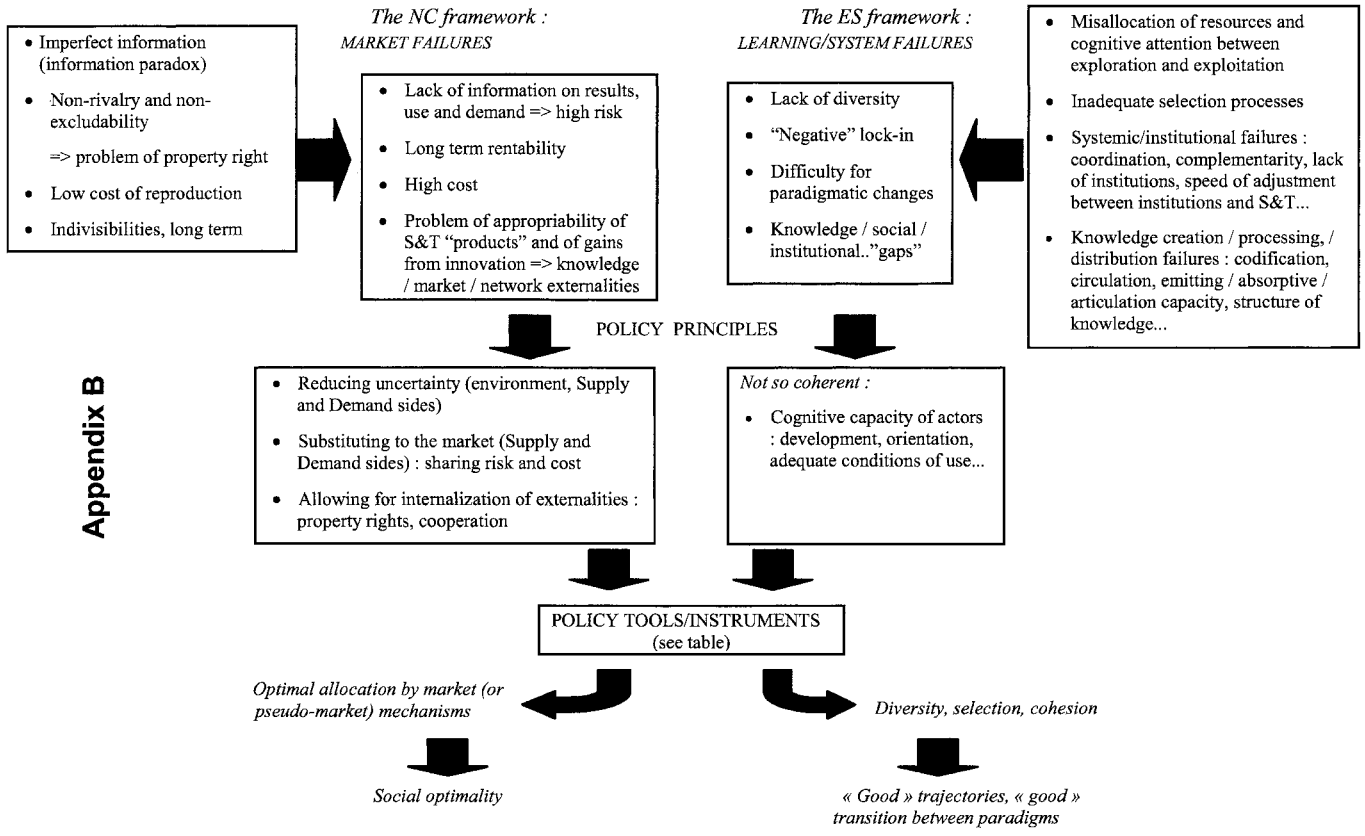

Fig. 1.1. The two dominant paradigms : failures, consequences and principles for policy action

Appendix C

Table 1.2. Policy tools and instruments in the two dominant paradigms

Interpretation in the NC framework	Basic tools and instruments of S&T policy	Interpretation in the ES framework
Reduce uncertainty and asymetries	Diffusion of Information Knowledge	Change the available knowledge-base; involves codification; change distribution of knowledge
idem	Public intermediaries of Information Knowledge	Idem; Reinforce coordination
Substitute to private investment for production of scientific output considered as public good	Public labs in Science	Increase and change the available knowledge-base by reinforcing exploration; involves codification; change emitting/absorptive capacity of labs
Partially substitute to private investment for production of technology considered as non-rival and partly excludable good	Subsidy to R&D activities of firms	Increase and change the available knowledge-base by reinforcing exploration; involves codification; change emitting/absorptive capacity of firms
Substitute to private demand (limited in time)	Public procurement	Orient selection process by reinforcing exploitation
Full guarantee of appropriability of technology considered as non-rival and partly excludable good	Property rights	Partial change of emitting/absorptive capacity
Internalize externalities : monetary (vertical cooperation), knowledge (horizontal cooperation); diffusion of information; risk/cost sharing	Cooperation Firms, All types firms and public labs	Change distribution and sharing of knowledge; reinforce coordination and complementarity; change emitting/absorptive capacity
Substitute to private investment for production of human capital	Education	Increase cognitive capacity
	Emergence of standards and plateforms	Orient selection process; involves codification
	Norms, regulations	Orient selection process; involves codification
	Other related policies	Orient selection