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ECONOMIC ASPECTS OF MILITARY RESEARCH AND DEVELOPMENT

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O. INTRODUCTION

In this note the development of new military items will be treated as an economic service analogous to the services rendered by commodities normally traded in on private markets. Particular concern is directed toward what may be termed exploratory development or applied research, that is, the development of prototypes quite far from immediate application, and particularly prototypes which represent reasonably radical changes from the current procedure. Such exploratory development, of course, shades off on one side into basic research and on the other, into the usual form of development or product improvement which is continuously going on with respect to any military end item.

Exploratory development in this sense is a commodity having a certain utility to government which is attained by the application of certain resources, both personal and material. As with respect to any other form of production of services and commodities, there is a problem of achieving an optimal allocation of available resources. Development is, however, a commodity with many special features, and we propose to examine these in order to suggest areas for empirical inquiry which will be useful in making recommendations for improving the current allocation of resources in this area.

It may be further remarked that most, though not all, of the problems of military development appear, even in regard to development of commodities for civilian use. This may be very useful in suggesting study of certain areas of development in commercial channels as well as of previous military development in order to draw conclusions concerning the best method of achieving a satisfactory rate of development.

We will follow the classic pattern of economic analysis. First the special conditions of supply and of demand peculiar to the economic service known as development will be considered, then the special incentive problems in this area and finally some consideration of alternative institutional arrangements for directing the allocation of resources.

1. THE CONDITIONS OF SUPPLY.

1.1 Uncertainty. By its very nature development involves a leap into the unknown. We cannot know in advance whether or not the development will be successful or what exactly will be achieved. If we did there would be no need for the development. Similarly, we cannot be sure of the costs involved, the resources that must be poured into the process. In short, choice problems in this area are special case of decision-making under conditions of uncertainty.

Production of a service or commodity under conditions of uncertainty is not peculiar to development. All production in fact, but especially that of agricultural commodities, is affected by uncertainty to a greater or lesser degree. In agriculture, for example, the weather has set a background of unpredictability to the possibilities of production. There and in other risky industries, special economic conditions emerge, particularly restrictions on the supply of credit and of capital. As we shall see, development--another risky commodity--has given rise to similar, and perhaps even more extreme, problems of the same type.

However, there is an important difference between the uncertainty inherent in development and that in the production of agricultural commodities. In the latter there is an irreducible unpredictability, at least in our present state of knowledge, which does not change from year to year. The "state of the world" is itself a variable over time. In development, on the contrary, where the aim is the acquisition of knowledge

the parameters being studied do not change over time. There therefore arises the possibility of sequential improvement of the information available or, to put it conversely, the reduction of uncertainty. The phenomenon is exactly the same as that in the sequential inspection of commodity lots where the decision to make further inspections can be better and better guided as more and more previous inspections have taken place. Development is after all a special case of learning, and experimental psychology indicates the learning is a process of successive approximations to a steady goal.

In technical language we may say that in development the a priori probability distribution of the true state of nature (the unknown performance characteristics of possible models) is relatively flat to begin with. On the other hand the successive a posteriori distributions after more and more studies have been conducted are more and more sharply peaked or concentrated in a more limited range, and therefore we have better and better information for deciding what the next step shall be. This implies that at the beginning the preferences among alternative possible lines of investigation are much less sharply defined than they are apt to be later on. This suggests, at least, the importance of having a wide variety of studies to begin with, gradually eliminating the less promising as more and more information is accumulated. At each stage we have information which will suggest expansion of certain lines of development and the curtailment or elimination of others.

It would be very interesting to examine some of the major innovations of the past, both in the civilian and the military fields, to see how this principle has operated. That is, has an initial wide variety of approaches gradually been narrowed down with experience to a few or one?

In such a process of sequential decision-making under uncertainty the role of information is of the utmost importance. At each stage the decisions about the next step should be based on all available information. This will require a flow of information among different projects which is incompatible with any extreme form of decentralization. The situation is quite different from the classic economic case of a world of certainty where there the price system can take the place of the spread of detailed information and the diseconomies of such spread achieve paramount importance. This is not to deny the importance of such costs; the preparation of progress reports and their assimilation by others can be a major effort. Economizing on these costs, for example by increasing the extent of informal communications such as personal contacts, is worthwhile. But the major point is that the price system cannot be used under conditions of uncertainty as a complete substitute for other methods of transmitting information.

The sequential process of removing uncertainty has another possible implication, which seems well substantiated empirically. The outcome of a particular line of research may be to a greater or lesser extent an increase of knowledge in an area quite distinct from that intended to be studied. This fact has several implications for policy: (1) any project must be considered as having potentialities for benefit beyond those directly anticipated, and so a somewhat more liberal policy in their approval is justified; (2) a high degree of communication among relatively unrelated studies will be useful in making engineers aware of the uses of their unexpected increments of knowledge; (3) provision must be made for making use of knowledge acquired in organizations whose main function may be quite far from the field in which development is sought.

While the existence of uncertainty is basic in development, its extent is perhaps worth some study. There is of course some element of predictability as to both the benefits and the costs of a given development project; otherwise no judgment could ever be made. In certain areas, at least, it may be relatively easy to state that certain performance characteristics can be achieved even without being able to specify too clearly how. Similarly, and probably more likely, it should be possible to predict with a fair degree of accuracy the costs of development. It is very likely that the possibilities of prediction will vary greatly among different fields and depend critically upon the extent to which the field has been reduced to a genuinely scientific status. It might well be worthwhile to study the errors of prediction either historically or by some type of controlled experiment.

1.2 The Supply of Skills. Since development is a special case of learning, and intelligence is defined as the ability to learn, it is not surprising that there will be tremendous differences among different engineers and other innovators in their ability to make successful judgments on the proper course of development. Behavior under uncertainty has an essentially creative aspect and seems incapable of being completely reduced to mechanical and well-defined rules. Certainly one has the impression from conversations and casual observation, as well as history, that the bulk of really significant advances are made by a very small handful, and that the possibilities of substituting larger numbers of less skilled personnel are extremely limited. The most critical problem, therefore, seems to be the recognition of this scarce talent and its most effective use. There seems little possibility, or at least much less possibility than in more static fields, of substituting good management or good institutional arrangements for sheer creative talent.

Unfortunately, of course, recognition of such talent is by no means a simple matter. Objective tests have never been devised to separate out creative people from others. It would seem well worthwhile to study something about the distribution of talent, insofar as it can be determined, the extent to which it is really true that inventions have been made by a small handful of people, and what if anything is known of the psychological and other preconditions of success in this area.

Though perhaps outside the scope of the present study, the problem of selection of talent has been the subject of a fair amount of study by psychologists, though, I believe, with little success. It might be of some interest to have this literature surveyed.

1.3 Economies of Scale. In any study of optimal allocation the problem of economies of scale may be of considerable importance. As is well known when there are economies of scale present it may be necessary to restrict the freedom of entry and of competition in order to take advantage of those economies. The usual sorts of things which give rise to scale economies may be present in development. There is a certain amount of overhead. Especially with uncertainty present it is useful to have a standby pool of research assistants and instruments whose size need expand less than proportionately to the volume of activity. The importance of communication among different researchers stressed above suggests some advantages to putting a number in easy communication with each other can be achieved by placing them in the same organization. It should be added though that we know too little of the psychology of scientific research and development to be sure of our ground here. There may be many good ideas whose premature exposure to the world might kill them.

In many lines of development it may well be that more skills are needed than can be found in a single person. In view of the scarcity of first-rate talent this may involve the maintenance of several highly

expensive researchers, a kind of indivisibility, which again would give rise to economies of scale. It is hard to assess the strength of these factors and certainly some writers seem to believe that development to a particular stage is just a matter of the number of man hours spent on it. A number of case studies of innovations may be of some use in casting light on this question though in view of all the uncertainties surrounding development it probably would be quite hard to achieve an answer.

However there is another factor operating. Development of a particular idea is really a stock rather than a flow. If it is desired to achieve the development as of a given time, then indeed there is a definite economy of scale. Even if we assume that development to a particular stage is just proportional to the number of man hours devoted to it, it is clear that achievement of a given stage at a given point of time will indeed be dependent on the number of men working on it at any given time. In the military sphere particularly, the value of development is strongly connected with the time in which it is achieved and it does appear therefore that economies of scale will, in this sense at least, be important in the production of developed ideas.

1.4 Relations Between Development and Production. A very crucial question in the organization of development is the relation between the development of items and their subsequent production. This relation works in both directions. Obviously development imposes strains on production. There is always an initial step in putting any change in a product into production. The more rapid the development the greater will be the difficulties encountered in production. Further, since the value of a developed article depends in part upon the ease of producing it, it is regarded by many as important that production considerations be given weight in the development process, at least towards its latter portion. Conversely, the experience derived during the development phase may be of considerable use in subsequent

production. For these reasons it is frequently argued that development must be correlated with production in the sense of being placed in the same organization. One would say in fact that this is a universally accepted proposition, the only problem being how far back in the development process the argument loses force. If these two are tied together, in effect the institutional organization of development is tied to a set-up which is deemed optimal for production. In those industries in which the bulk of the product is taken by the government, the institutional arrangement seems to be something of the following: A small number of firms are maintained in business enough to presumably supply a certain amount of competition. At the same time these firms are protected from new entrants on the grounds that the learning needed by newcomers is too costly for the government to, in effect, support. Further, there would be no economic justification, it is alleged, for the wastage of capital engaged in the older firms. It is assumed that because of conditions of economies of scale in production that such an arrangement gives reasonably inexpensive production. Without entering into the merits of this point, the question is raised whether such an arrangement is also optimal for development. It certainly involves a very severe restriction on the freedom of entry into the development business. Also within any given firm there is competition for the engineering talent as between production and development. For such an allocation to be optimal, the incentives for the firm must be correct in the sense of reflecting the relative social desirability of the two.

2. DEMAND CONDITIONS.

2.1 Attitudes Toward Uncertainty. Since the output of development is apt to be very uncertain the attitude of the government toward risk-bearing

is of some relevance in the decisions being made. However, it seems pretty hard to evaluate the relative risk-aversion or risk-preference that the government does or should have, and probably little can be said on this subject.

2.2 Quality vs. Quantity. As already noted, development is very apt to be competitive with production and a very critical decision may have to be made in certain areas as to the relative importance of improvements in quality and of increases in quantity available. It has been held, especially in the post-war period, that in many branches of armament small quality differences are of the greatest importance. To the extent that this is true, the emphasis on production must be considerably diminished and it would seem that the organization of the supplying industries should be oriented much more to rapidity of development than towards economies of production. As, for example, airplanes become more and more complex the chances that they will be produced in anything that can be regarded as mass quantities becomes less and less and the emphasis in design upon producibility must be correspondingly diminished.

2.3 Complementarity of Different Developments. Developments in many diverse lines are in many cases ultimately intended to fit together into a system. The decision-making on the part of the government as to development will inevitably be affected to a certain extent by the prospects for development not only in the particular area under consideration but also in other areas complementary to it. Probably this aspect if anything has been greatly over-stressed in recent years but, of course, it would not be possible to ignore it completely.

2.4 Monopsony. Since the government is the only demander for military items there is automatically a monopsony situation. In and of

itself this should be an asset rather than a liability in the allocation of resources since the government ideally could reproduce through its economic power any institutional arrangement that it regarded as optimal. The danger is the usual one whenever there is an extreme concentration of power--the lack of checking. It has sometimes been pointed out that Army-Navy rivalry, for example, has served a useful purpose and there may well be grounds for deliberate decentralization within the government. There may be a strong case for different agencies of the Defense Department to pursue different policies in development simply to avoid having promising lines suppressed through incorrect judgment on the part of any one person. The fetish of efficiency through coordination must be carefully resisted.

3. THE PROBLEMS OF INCENTIVE.

3.1 Inappropriability of the Product. The basic incentive problem in the field of development, which arises both in the civilian and the military spheres, is that the product is not very well adapted to appropriation as property. Patent laws provide only a very meagre amount of protection to the developer of a new idea. It has frequently been remarked by commercial firms that they regard their advantage derived from research as being rather that of being ahead of their competitors than the advantages obtainable by taking patents on the results of their research. This probably should be investigated somewhat more carefully. This means that no correct market for development can be set up analogous to that for a more tangible commodity.

Another difficulty of the same type is that of the evaluation of the results of a development. It is quite difficult to know just how valuable a result is in commercial or military terms even when it has already reached the prototype stage. Hence again severe restrictions to the possibility of setting up a well-defined market.

3.2 Rate of Return on Development. Because the market for development in and of itself is so poor, their rate of return on development is apt to be very low. Development contracts have not tended to carry rates of return which will be comparable with the return available on production contracts. This means that the incentive to undertake development must in practice be something else than the actual rate of return of the contract itself. Frequently it is the expectation that the production contract will go to the firm which has succeeded in making a successful development. This approach is connected with the previous discussion of close relationship between development and production. It certainly has the effect of restricting entry into the production field even more than otherwise would be the case, and at the same time restricts development contracts to firms that can undertake the subsequent production, since the others would not find it profitable. Another possibility, which seems to have been more important in the electronics field than in airframes or engines is the amount of experience and byproduct of learning acquired in a development contract. A firm that finds some development profitable will always like to have some of it paid for even if the rate of return of the development contract itself is small. In the case of private firms the advantage to development is, of course, the subsequent production resulting therefrom and, as noted before, the lead over competitors.

3.3 Competition and the Flow of Information. Any situation involving competition must imply some restrictions on the degree of information that will flow across firm boundaries. If the firms are competing with the expectation of making profits there will always be strong incentives toward secrecy. This involves some clear difficulties in that the incentives for private profit do not correspond completely with those of greater social

gain since, as seen above, a full flow of information is important in sequential decision-making under uncertainty.

3.4 Restrictions on Entry. To the extent that development is tied to production and it is desired to restrict entry into the latter field there will automatically be restriction in the field of development. This means again that the incentives will not be working completely correctly in that individuals not currently engaged in production will have difficulty in competing in the area of development. It has frequently been remarked that it is perhaps even more important to have free entry in the realm of ideas than in the realm of finished products.

3.5 Legal Restrictions. There is no question that a good deal of handicap is placed on the establishment of proper incentives by legal restrictions of one type or another. To the extent that the government itself could undertake any development it is restricted greatly by current Civil Service regulations. The possibilities for promotion and for competition in the market for skills are greatly restricted. Similarly, conditions surrounding the awarding of development contracts, especially in regard to provisions for payments, and for the methods of negotiation, have at least in the past operated to restrict entry and to restrict free competition by setting up excessive financial conditions for entry.

3.6 Whose Incentive? Classic economic theory thinks of the firm as the main organizer of production. To the entrepreneur is delegated the suboptimization so important for efficient operation and management of resources. For the case of development, as has been argued before, the critical factor is likely to be the activities of a very small number of talented individuals. It is their incentives primarily and not those of managers that are really to be considered. It is probably worth the investigation to see to what extent the firm, considered as a managerial unit, contributes

to the efficiency and speed of development as contrasted with its contribution in merely choosing the right people. Can the firm really be thought of in the area of development as an organization with continuity, with sufficiently unified qualities to be thought of as almost a single individual, or is a firm merely a place in which the innovator hangs his hat temporarily? In the commercial field there is indeed evidence that some organizations, most conspicuously Bell Telephone Laboratories, have maintained scientific leadership over long periods of time, but it would be interesting to examine to what extent this is typical.

3.7 Pecuniary and Non-Pecuniary Incentives. It may well be examined to what extent non-pecuniary incentives play some role in motivating innovations. Certainly in the realm of pure research motives such as prestige, emulation, and the desire for standing are probably just as important, if not more so, than the desire to get a pay rise. Certainly pecuniary motives must play a much stronger role in invention proper, yet I suspect that even here may be evidenced the desire to get an idea carried out or a desire for prestige or to get ahead of one's rival in terms of beating him to the punch may still be a potent factor. Competition may well be important, not so much because of the pecuniary possibilities inherent (which are greatly blunted by the special types of contracts needed in this field) as for the desire not to be outshown by others.

4. ALTERNATIVE POSSIBILITIES OF INSTITUTIONAL ARRANGEMENTS.

4.1 Joining Development and Production. A fairly common pattern in the past and the present has been the carrying out of development even of a fairly exploratory nature by the same companies that engage in production. This can have some very pernicious consequences. If the production side is to be kept "healthy" by restricting entry into the field then

automatically, as already noted, development will be restricted to a fairly small group of companies. The stimulation of competition whether at the pecuniary level or the emulative level will be greatly weakened. On the other hand, of course, the advantages, also noted, of joining production and development cannot be completely overlooked. It is clear that when a development is of a very minor nature it is probably best tied to production, but, as one goes further and further away from present models there is a stronger and stronger case for divorcing development and production or at least not restricting development to the companies now engaged in the business of production.

4.2 The Competitive Models. Welfare economists might be tempted to think of a purely competitive situation, namely, admitting firms freely to the development field and paying them according to some market mechanism. Now the competitive model must imply a full working of the price system and the difficulty here is that of setting up proper markets. As we have already noted development is hard to market because of its inappropriability. It is true the government in a monopsony situation could deliberately pay for development on some basis which preserves the property rights of the individual in a way that would be impossible in a market with competition on both sides. Even so, however, it must protect each firm against stealing of ideas by rivals and this seems pretty hard to enforce. However, a second difficulty is that whenever there is uncertainty the price system loses its simplicity. Properly speaking, there would have to be a complete market for risk-bearing so that a firm could, in effect, be insured against its line development being a failure. Some approximation to a competitive model might be achieved by having the government announce that for the successful completion of prototypes with prescribed specifications there would be fixed prizes awarded, leaving it up to the individuals whether or not they would

choose to take the chance of winning these prizes. These prizes might be offered to individuals and to firms or in some other simple way. However, the absence of a market for exchanging risks of phase developed means, in effect, that a great many firms can be excluded because of capital rationing, which is a more aggravated form of a phenomenon that already exists in such areas as agriculture. It is, of course, impossible to establish a market for insuring risks of non-development because of what insurance men refer to as a moral factor: there is no way of separating an intrinsic impossibility for methods to work from simply a failure on the part of a firm or individual to do the work successfully or to work hard enough at it.

Nevertheless, the pure prize idea seems to have some merit in that it introduces the idea of payment according to the value of services rather than according to the amount of work done. It is possibly worth considering as a supplement to other forms of contracts. A prize is roughly a lump sum equivalent of the royalties which are common in commercial practice and which do indeed provide some incentive. The reason why a lump sum is probably better than a royalty paid according to the number of items used is that the latter is at the determination of the government and there is no particular reason why the inventor should have to speculate on the extent to which the government will use his invention. The government itself will probably be better advised to make this determination and incorporate it into the form of fixed price.

4.3 Modified Competitive Models. In practice the government has used a variety of contracts which in one form or another have the effect of sharing the risks. If the development contracted for takes longer than expected the government bears all or a great part of the risks. This is designed to overcome the capital rationing noted in the previous section, and of course has the usual effect of dulling incentives.

More important perhaps it shows clearly the impossibility of complete decentralization. If the government is going to risk the money, the government must make the decision as to whether it is worthwhile. There is simply no way for the government to relieve itself of the obligation of deciding on the wisdom of alternative lines of investigation by reference to competition since the competition will not work in the proper way under conditions of uncertainty. Several lines of investigation open themselves up here. Are there any ways of comparing the performances obtainable under different types of government contracts? Are other contract forms other than those now in existence reasonable? Several, indeed, can be easily thought of; for example, a payment which depends partly on costs and partly on the degree of success measured according to some standards. It may also be interesting to look at foreign experience in these matters. Another question that is suggested is what, if any, generalizations can be made about the type of directives that the government has to make and what it should form its judgment on. In many respects, of course, its judgment is formed not according to its judgment of the technical possibilities of a given line of development, but rather according to its confidence in the firm or the scientist directly responsible for undertaking the work. This is, of course, very reasonable.

4.4 Research Institutes. If we agree that it is the skilled workers and not the managerial talent that is primarily important in development, the idea of setting up research institutes seems to be a very attractive one. This, indeed, has been very important in Germany and the establishment of private non-profit corporations by the Air Force, such as RAND itself, shows that this method of organization is regarded as having some potentialities even here. If the research institutes are established with a sufficient

degree of flexibility there is no reason why they cannot provide incentives in the form of salaries and possibly royalties to their members which will provide all the necessary pecuniary incentives for development. Further, there will probably be much more chance for an individual engineer or developer to get his name attached to specific developments and so to supply incentives of prestige and emulation that may be very important. An organization which has as its primary object the generation of new ideas is apt to be a much more receptive place than an organization whose primary concern is production.

4.5 Civil Service. The research institute idea amounts to simply having the government through some mild indirection do all or a great deal of the development itself. It is common to remark that Civil Service regulations pose such stringent limits that the government cannot carry it on successfully, and there is probably a good deal to be said for this point. Research institutes and other non-profit organizations are in many respects simply a method by which the government evades some of its own legal restrictions. However, it probably would be useful to compile a study of the extent to which the government has, both in military and non-military fields, actually carried on important development. Work of the NACA particularly might be profitably compared with the research done by the airframe companies before World War II. I have the impression that even in an area like power plants the work of Wright Field had considerable importance before the war. The work of the United States Public Health Service in developing a practical method for manufacturing penicillin is another example of government research, and indeed there is a whole host of developments in the medical sphere. I think one should examine these with some care to see just how satisfactory the record of the government here and in other countries has been whenever they have directly engaged in research.

4.6 The Government as Decision-Maker. Whatever institutional arrangement is adopted for the execution of exploratory development, it has already been made clear that the government's decision-making role cannot be abdicated. There seems to be clear evidence of considerable imperfections here. The fear of making a mistake seems to give rise to a conservatism uncalled for in such an uncertain field. The long delays in the development and procurement cycle are possibly another reflection of this fear of committing a mistake, little cognizance being taken of the risks of not pushing development in areas where it is feasible and useful.

It seems very possible that a considerable decentralization of decisions on development would be in order--avoidance of duplication is not necessarily a virtue. Differing judgments as to the desirability of particular developments should be allowed full chance to operate without excessive coordination or control, which is better advised as more information has accumulated rather than in the preliminary stages. The free entry of ideas should not be unnecessarily interfered with by the government any more than by private firms.

