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INNOVATION AND DEVELOPMENT

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INNOVATION AND DEVELOPMENT

A Reveiw of some Work at the IDB/CEPAL Project

My purpose here is to review three papers of the IDB/CEPAL project and relate them to three issues concerning the relationship between innovation and development: The character or type of innovations; the inducements to innovate and the development of technological capabilities. Two papers deal with the technological history of individual industrial plants -- P. Maxwell's paper on Acindar's Rosario Steel Plant and the paper by J. Katz and collaborators on Ducilo's Rayon Plant; the third, by G. Vitelli, reviews the Argentine Construction sector.

The first two papers have very well defined objectives which involve first a description of the various technological changes that occurred during the period analyzed and second an analysis of their determinants or inducements and of their impact on the growth of output or labour productivity. The last paper's objective is, on the other hand, much less defined. It seeks to confirm or disconfirm a series of stereotypes held by the public on the Argentine construction industry, in particular with regard to concentration, importance of foreign capital and origin of innovations. While the description and analysis is rich and insightful it lacks the focus and structure of the first group of studies. Correspondingly, while my review of the plant studies will deal centrally with the character of the innovations and with the inducements to innovate, I have decided to address the issue of development of technological capabilities while reviewing the sectoral study on the Construction Industry.

Section I will deal with output-increasing innovations, the importance of which has been demonstrated in the steel and rayon plant studies, while Section II will propose an over-all framework for the determinants of innovation. In Section III I will try of relate the concentration and foreign capital impacts discussion of the construction industry to ussues in Industrial Organization and to the issue of technological dependence. Finally, in the Appendix we present a simplified model of output-increasing innovations.

I. *Output-Increasing Innovation*

The history of the steel and rayon plants shows a significant impact of innovation on the growth in labour productivity and on the growth of capacity. Katz et al. show that labour productivity[1] grew by 46 per cent during the 1941-67 period and that 2/3 of this growth can be attributed, by and large, to disembodied technological innovation involving a local R & D and engineering effort. One quarter of this growth is associated with technological change embodied in purchases of new capital goods. Moreover, more than one half of the disembodied technological change is

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[1] Net of the effects of changes in capital per man and of "homogenization" of output.

fundamentally output-increasing, that is, leading to a greater output from a given plant.[2] Maxwell, on the other hand, shows that approximately 54 per cent of the change in capacity of the steel making section of the plant and 100 per cent of the increase in the capacity of the billet mill was due to technological innovations and that most of these were of an output-increasing type[3] while the remainder was due to additional capacity installed. When defining output-increasing innovation both papers look at the main motivation or objective of the innovation and point out that, although the outcome generally leads to a reduction in costs, they are not the usual cost-reducing innovations traditionally considered in economic theory.

My purpose here is to provide some structure to this notion of output-increasing innovations and to relate the findings mentioned above to a wider experience. It seems to me that the emergence and elimination of output bottle-necks is a normal phenomenon in a successful process of economic growth; the clearest example that comes to my mind is that of cotton textiles during the Industrial Revolution. The increased demand for cotton textiles in 18th-century England could not be supplied at constant cost and without lags by the traditional putting-out system based on traditional technology (e.g., the spinning-wheel). This "bottle-neck" was overcome by a succession of new output-increasing spinning machines -- the jennie, frames and mules -- and a new organization of production --

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2 I refer here to the modification in spinning leading to higher spinning speeds, principally "tube-spinning."

3 The most important events here are the building of shaft furnaces leading to the open-hearth furnaces (1949) and the oxygen-injection technique. Both increased the rate of output of the existing furnaces.

the factory system.[4] The success of the spinning innovations, in turn, created a "bottleneck" in weaving which in turn elicited weaving innovations, and so on. Numerous examples of creation and elimination of "bottlenecks" have been noted in the economic development of present-day advanced countries with innovations playing a central role in the process. This seems to be such a central feature that a realistic model of growth and development should consider it explicitly. The point I would like to stress at the outset is that while institutional factors such as delays in obtaining government authorization for conventional capital expansion undoubtedly played a role in triggering output-increasing innovations in at least one of the case studies analyzed, innovations of this character are more common in the real world and play a much more important role in growth than what would normally be assumed. Moreover, it is not surprising that economic theory does not consider these sequences since its framework is essentially a static one and its assumption of perfect (i.e., costless and instantaneous) intersectoral capital mobility and intrasectoral malleability precludes the existence or emergence of production bottlenecks.

A bottleneck may be defined as a situation where an actual increase in demand cannot be instantaneously satisfied at unchanged cost by conventional means. That is the emergence of a bottleneck increases the relative profitability of an innovation whose primary purpose is to increase output.

I would like to be a bit more explicit, first in explaining the reasons for the emergence of a bottleneck in production (once exogenous demand has increased). These may include the following:

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[4] For a comprehensive examination see D. Landes, *The Unbound Prometheus*.

1. Costs of adjustment: The conventional capital goods can only be supplied to the firm with delays or at higher costs

2. Skill constraints: E.g., a wartime increase in the demand for guns in the face of a given, non-augmentable stock of skilled artisans.[5]

3. Institutional reasons: E.g., delays in getting government permits to expand.

Situations like these hamper the possibility of the firm benefiting from exogenous increases in demand, if they attempt to produce additional output by conventional means. They correspondingly increase the relative profitability of alternative means (i.e., of innovation) which enable more output to be extracted from existing, fixed, non augmentable factors. This, even when conventional means are more efficient in producing the original output level.

Some additional comments should be made:

1. The basic reason for a bottleneck is the delay in expanding output by conventional means.[6] There usually will be some possibility of reducing this delay by paying a higher price for the *specific* factors employed in the sector.

2. Innovation is only one alternative for time-consuming and costly conventional output expansion. Simply adding perfectly variable factors (e.g., labour) may be another means of increasing output at a fast rate. This need not always be feasible or efficient.

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5 This situation led to the introduction of machine-tool innovation in gunmaking. See Rosenberg. Technology in American Economic Growth

6 Thus, relatively disembodied innovations may become very attractive during periods of bottlenecks. This certainly was the case in both the Acindar and Ducilo plants.

3. While the innovations elicited by a bottleneck as defined above will have to be "output-increasing" they need not be cost-reducing in the sense that the unit costs of additional output with the new technology should be lower than unit costs prior to the emergence of the bottleneck, or that unit costs for the original output level should decline. However, total profits from using the innovation to expand output should exceed total profits from conventional expansion. With small differences in the rates of output-expansion under both alternatives, this would imply lower unit costs for the additional output elicited by the innovation.[7,8]

4. A wider concept of bottleneck would cover situations where existing output levels cannot be maintained by conventional means, even at higher unit costs, due to machinery breakdowns, depletion of natural resources, or other factors.

To summarize, once we assume that additional specific factors of production can only be obtained with delays and at higher cost, there is room for considering a category of innovations which we can term output-increasing.[9] Moreover, since the industrial locus of these bottlenecks shifts through time, we may expect a corresponding shift in the locus of innovation of this type. The case studies considered seem to confirm that bottlenecks and innovation which increase output are pervasive and significant in their effects on growth.

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7 Taking into account fixed R & D costs in developing the new technology.

8 In practice, many output-increasing innovations reduce unit costs, but certainly not all of them do.

9 The model in the Appendix indicates conditions under which a bottleneck is necessary and sufficient to elicit output-increasing innovations.

II. *A Typology of Inducements to Innovate*

The character or type of innovations -- product versus process, cost-reducing vs output-increasing -- has been distinguished in the literature from the inducements to innovate or determinants of innovation (e.g., changes in relative factor costs). The case studies considered in this paper have also referred to the impact on innovations of macro-economic or public policy variables such as the rate of exchange, regulation of working conditions and the state of the economy. These variables should be considered as affecting the more immediate inducements to innovate, such as the cost of capital or labour, rather than constituting separate categories by themselves.

Economic theory has concentrated until very recently on changing relative factor costs as the main inducement mechanism for technological innovation.[10] The study of economic history and the recent literature on Industrial Organization and the Economics of Innovation have also emphasized the role of "scale" variables (like size and growth of markets and firms) and the role of market structure on the inducements to innovate. These traditions (plus others) are not fully integrated and it may be useful, in the light of the multiplicity of inducement mechanisms operating in our case studies, to attempt some kind of classification which may enable us to organize existing knowledge. The distinction between exogenous (with respect to the firm) and endogenous factors suggested both by Maxwell and

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[10] The most complete discussion of this inducement mechanism is found in H. Binswagner's paper: "A Microeconomic Approach to Induced Innovation," *Economic Journal*, 1974.

by Katz et al. is adopted.[11] The scheme is as follows:

Inducements to Innovate

A. Exogenous to the Firm

1. Changes in relative factor costs
2. Growth in market
3. Rivalry
4. Increases in Technological Knowledge
5. Stage of product or innovation cycle.

B. Endogenous

1. Firm size
2. Imbalances and disequilibria.

We will briefly consider each type of inducement, the nature of innovation elicited, and its relevance for the case studies.

A.1. This would induce cost-reducing innovation, like those saving on celullose and caustic soda in the Ducilo plant and those procedures associated with improved scrap quality control, scrap selection and scrap densification in Acindar's Rosario plant.

A.2. We have already discussed output-increasing innovations, the conditions for their existence and their significance for the cases studied. A related "scale" inducement is that shown by Schmookler.[12] The number of

[11] In a recent paper by D. Mowery and N. Rosenberg, "The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies," a distinction between "needs" of a firm and market need or demand was suggested. This largely corresponds to the exogenous/endogenous distinction.

[12] See Schmookler, *Invention and Economic Growth*, Harvard Univ. Press.

patents obtained on capital goods inventions was demonstrated to be proportional to investment in the industries utilizing those inventions (i.e., proportional to the market for the corresponding class of capital goods). Schmookler's framework implies nothing about whether the inventions would correspond or not to output-increasing innovations.

A.3. The Schumpeterian hypothesis that rivalry induces innovation has been subject to empirical research in the Industrial Organization literature. The basic problem in this literature is the lack of a satisfactory notion of rivalry. Empirical studies use the industry concentration ratio as the main independent variable, but the view that more concentration implies less rivalry is seriously deficient.[13] There seems to be some support to the view that concentration promotes innovation, at least up to a certain level.[14] Both case studies show very clearly that increases in rivalry have led to an intensification of innovation and, moreover, that a lot of the innovation was new product innovation (ridged and ribbed reinforcing bars, special steel grades in the case of Acindar) or innovation leading to improved product quality (Ducilo's case). There seems to be very little theory on the nature of the strategic response of firms to increases in rivalry, but there is no doubt that product innovation rather than price competition plays a major role, at least in high-technology industry. An issue yet to be considered in this literature concerns the type of firm

[13] A good summary can be found in J. Markham: "Concentration, A Stimulus or Retardant to Innovation," in *Industrial Concentration: The New Learning*, H. Goldschmid, M. Mann, F. Watson (eds.), Brown and Companies, 1974.

[14] See F. Scherer, "Market Structure and the Employjment of Scientists and Engineers," *A.E.R.*, 57, June 1967.

which will control the main mass market relative to the type(s) that will be active mainly in the less-important sub-markets and user segments.

A.4. Increases in technological knowledge may induce or trigger innovations, especially when an unfilled "need" is clearly perceived. Langrish et al. have used the term "discovery push" or "technology push" to describe an innovation process that is initiated or triggered by new knowledge without a clear view of the need that it will fill.[15] The proportion of these innovations that are "major" is higher than when innovations are demand-pulled. No clear case of technology-push has been identified in the case studies.[16]

A.5. The "stage" in the innovation or product cycle cannot be properly characterized as a separate inducement category, since it presumably involves elements of other categories (e.g., market size, extent of rivalry). Product cycle theory rather represents an attempt to look at the inducements to innovate in a dynamic setting. A central proposition is the reduction in the rate of innovation through time.[17] The task of determining the supply and demand factors explaining this tendency (or its opposite) is still incomplete. Concepts like the specificity of the process technology

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[15] Langrish et al., *Wealth from Knowledge: A Study of Innovation in Industry*, New York, Halsted, John Wiley, 1972.

[16] F. Scherer has interpreted some of the interindustry variation in patented inventions as due to differences in technological opportunity. But this variable has not been measured directly and alternative interpretations as possible. See his "Firm Size, Market Structure, Opportunity and the Output of Patented Inventions," *A.E.R.*, 196 .

[17] See Vernon, R., "International Trade and International Investment in the Product Cycle," *Quarterly Journal of Economics*, 1965.

used and the extent of user need determinateness (or specificity of demand for product type) have been proposed to supplement conventional supply and demand variables.[18]

B.1. This is clearly a major determinant of the inputs to innovation and of the outputs.[19] The influence of this variable seems to me to have been understated in the case studies considered. The growth of a firm enables a greater specialization of function and should be regarded as a main determinant of the extent of "activities of plant personnel (and plant divisions) who are concerned with increasing plant efficiency, and who are on the look-out for opportunities to do so."[20] I suggest that the magnitude of at least some of the quality control, preventive maintenance and planning activities of Acindar is related to its size and not only to emergencies like deterioration of plant.

B.2. The case studies analyzed have emphasized the role of imbalances and disequilibria in the production process as a stimulus to innovation.

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18 See Abernathy, W., and J. Utterback, "Innovation and the Evolving Structure of the Firm," Harvard Business School Working Paper, June 1975, and M. Teubal, "On User Needs and Need Determination: Aspects of the Theory of Technological Innovation," to appear in *Proceedings of Symposium on Industrial Innovation* held at the University of Strathclyde, September 1977.

19 See Mansfield, *Industrial Research and Technological Innovation*, Norton, 1968. An important issue is whether R & D expenditures as a fraction of sales increase or decrease with firm size. Empirical work has identified a critical size which varies from industry to industry. See F. M. Scherer, *Industrial Market Structure and Economic Performance*, Rand McNally, 1970.

20 Quoted from P. Maxwell, p. 165.

Equipment malfunctions and the ironing-out of production problems have led -- following Maxwell -- to "cognitive" learning upon which process improvements were bred; unused capacity in particular stages has spurred process improvements in other stages, and routine monitoring and control of performance led to an accumulation of technological knowledge which enabled improvements elsewhere. These stimuli are not necessarily dependent on changes in the external circumstances facing the firm although they do determine the innovative outcomes in process triggered by such changes. The basic characteristic of such stimuli is that there is no describable equilibrium situation where they would cease to have an effect. The reason for this, following R. Nelson, is that technological capabilities are not wholly describable a priori and that learning continually opens up new possibilities for improvement. Concepts like "focussing devices" and "natural trajectories" may be useful in describing the particular technological paths followed in response to stimuli of this kind.[21] Both case studies here shed considerable light on this "disequilibrium" category of inducements to innovate, and have shown that these are technology and/or firm specific.

III. Developing Technological Capabilities: Issues arising from a study of the Argentine Construction Industry

The character and extent of innovation should be dependent on the character and magnitude of the various inducements described above. Systematic

[21] See N. Rosenberg, "The Direction of Technological Change: Inducement Mechanisms and Focusing Devices," 1969, reprinted in *Perspectives in Technology*, Cambridge University Press; and R. Nelson, "In Search of a Useful Theory of Innovation," *Research Policy*, 6, 1977.

relationships linking market size, firm size and concentration ratio with innovation input and/or output have been found in cross-section studies of U.S. sectors and firms. Practically no reference exists in this and in related literature on a determinant of the supply side which we might term technological capabilitis or innovation skills.[22] While omission of this variable may be serious in cross-section studies of innovativeness in the U.S., it may be catastrophic when attempting to explain innovativeness through time in developing countries. Moreover, if the micro-economic studies do indeed show with sufficient generality the importance to productivity growth of endogenous R, D, and engineering efforts, a new "model" of development should indeed focus on this variable. The emergence and development of technological capabilities would then become a major concern of students of development and of policy-makers alike.

In this connection, C. Cooper[23] has extended Arrow's proposition of a tendency for a market economy to under-invest in the production of information to the situation of developing countries. The high private risks of contracting local factors to design and construct engineering projects and the externalities generated will lead to an underemployment (relative to the social optimum) of these factors. They will consequently be deprived of an essential ingredient to the growth of local technological capabilities -- the possibility of learning by doing. The implication is that the State should subsidize private firms who employ local factors in technology

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[22] Although a related variable "Technological Opportunity" has been suggested in the literature, very little effort has been made to define or measure it.

[23] In *Science, Technology and Development*, Frank Cass, 1973.

projects. As we will see, this has not always been the case in Argentina, as the construction sector study clearly shows.

G. Vitelli's study describes technological and market trends in the Argentine construction industry and suggests explanations which focus on the changing nature of world innovation in this industry, on changing national needs for construction, and on the contracting policies followed by the government. The main tendencies observed are: a decline in the relative importance of local patents taken out by local inventors (e.g., from 72 per cent of road construction equipment patents in 1920 to 15.7 per cent in 1960/75); and increased share of patents on materials and equipment relative to patents on construction designs or systems; a high and possibly increasing concentration and share of foreign capital in selected non-housing construction sub-markets (e.g., building of dams, bridges, etc.[24]). Historical accounts of the developments of construction technology increasingly involving more expensive capital equipment developed abroad (e.g., heavy earth-moving equipment) together with the increased complexity of infra-structure type projects are seen as underlying causes of these tendencies. Of particular interest is the role played by an additional variable, namely, the contracting policies of the Argentine Government, in both helping to create and helping to preserve an oligopolistic, foreign-dominated market structure in big engineering projects. An analysis of these policies and of their impact on the economy seems to me to be a fruitful line of further study of the construction industry.

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[24] A cross-section of the industry for an unspecified year shows that sub-markets having a higher share of foreign patenting are both more concentrated and have a higher share of output produced by foreign firms.

The Argentine Government's public contracting policies allow only a sub-set of potential offerers to participate in a bid. These firms should conform with minimum "scale" requirements, should own the required capital equipment and should have prior experience with the technologies involved. This policy is a "low risk" policy which, while assuring satisfactory completion of public projects, almost systematically excludes local firms and especially local firms coming up with locally developed but untried technologies. The static benefits may be "satisfied" at the expense of restricting a learning process with future dynamic benefits.[25]

In contrast to this Vitelli points out the possibilities of local creativity, experimentation and learning that existed previously, in the pre-1940 period.

The basic theme which a study like Vitelli's could address is the role of public policy in the development of the technological capabilities of the country. There are several issues that should be addressed:

1. What is the nature and what are the determinants of the learning process? What hierarchy of skills is relevant for understanding the development of local technological capabilities and their impact on the economy? Maxwell has devoted considerable attention to this question while Katz looked at some learning externalities benefiting suppliers and clients.

The extent of overdesign in process plants and the degree of complexity of imported construction technology has also been shown elsewhere to affect local learning. The analysis of some individual construction projects

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[25] In addition, a monopoly or oligopoly in the supply of infrastructure construction may lead ceteris paribus to a higher price and hence to static inefficiencies as well.

would yield some additional useful insights in this respect.

2. Does a high share of foreign capital in local engineering projects imply low domestic learning and, conversely, does a high share of local firms automatically ensure a high rate of learning? The answer to either question is probably not clear-cut.[26]

3. The nature of the balance between the potential static advantage from commissioning a project to a foreign firm and the potential dynamic advantage of commissioning it to a local firm?[27]

4. The extent of government subsidization or preference to local engineering firms.(This will depend on whether the learning effect is or is not concentrated in the sub-markets actually controlled by foreign firms).

An important aspect of the policy question which is consistent with Vitelli's framework is the public attitude towards entry of new/small firms and the means to promote entry. In the context of U.S. Federal Support to the electronic industry is was stated:

> While direct R & D support tended to go to established firms, many smaller organizations were also supported often on the basis of unsolicited and sole purpose proposals, which served

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[26] The positive attitude of the Israeli Government with respect to foreign investment may in part reflect an awareness of the skills they bring and of the learning possibilities that they open. On the other hand, a simple policy of granting a contract to a local firm may not lead to learning if it subcontracts everything to a foreign firm (would Futaleufú be an example?). An answer of this issue seems to me to be essential because the mere presence of foreign firms and even of oligopoly may or may not be beneficial in the short run.

[27] Assuming the answer #2 to be a positive one.

> to assist their entry into the industry.... Recent trends appear to have reduced chances for entry into the electronic industry. These trends include greater defense reliance on established suppliers, a greater degree of use of cost criteria in procurement and a lessened willingness to accept sole-source and unsolicited proposals.[28]

Despite the differences in policy objectives, the above statement is indicative of the policy instruments and trade-offs involved.

Conclusions

We have attempted to link a discussion of the three case studies to three general issues in the area of innovation and development: the character of innovations, the inducements to innovate, and the development of technological skills. In the process output-increasing innovations have been inserted into a wider context; a classification of inducements has been proposed which allows for equilibrium-type inducements and disequilibrium-type stimuli; and finally, some preliminary issues for research into the learning process have been proposed.

Concerning the case-studies themselves. The two studies of innovation at the plant level belong to and -- thanks to their high quality -- contribute to define a particular tradition of research in the micro-economics of innovation. The objectives of the analysis are consequently clear and the task of the reviewer is straightforward. A different situation prevails with respect to G. Vitelli's study of the Argentine Construction Industry,

[28] From J. Utterback and A. Murray: "The Influence of Defence Procurement and Sponsorship of R & D on the Development of the Civilian Electronics Industry," Center for Policy Alternatives, M.I.T., June 1977.

probably due to its being a pioneering attempt in this direction. Its comprehensiveness reveals the lack of a clearly defined set of objectives which the sectoral analysis should address. Given that the mere fact of increasing concentration and increased role of foreign capital in the sector is not necessarily undesirable (at least to me), I suggested linking the analysis to one possible area of conflict between national objectives and private (and specifically foreign) interests. Consideration of the learning process would also imply linking the analysis of a sector with the analysis of specific projects. This is a highly desirable approach for studies of innovation.

APPENDIX

Output-Increasing Innovations: Necessary & Sufficient Conditions

We want to discuss the conditions under which a bottleneck will elicit capital stretching or output-increasing innovations in terms of a very simple model.

A single producer is confronted at t. with the following demand and production conditions:

$$\begin{cases} Q^d = b_0 p^{-\eta} & b_0 > 0, \quad \eta > 1 \\ Q^s = aK \end{cases} \tag{1}$$

where K and Q are capital stock and output, p is price, and b_0, a, and η are positive constants. Assume also that K at t has been optimally adjusted to maximise profits, Π_0, given (1). Let that value of K be K_0 and the corresponding value of p be p_0. K_0 must then satisfy:

$$\max_K \Pi = \max aK(p - C_0)$$

where $C_0 = \frac{r}{a}$ are unit costs (r is the rental rate of capital), and [from (1)]:

$$p = \left(\frac{b_0}{aK}\right)^{1/\eta} \tag{2}$$

The condition $\partial\Pi/\partial K = 0$ leads to the following:

$$\left(\frac{b_0}{aK}\right)^{1/\eta} = \frac{r}{a}\frac{\eta}{\eta - 1} = p_0 \tag{3}$$

or, alternatively,

$$K_0 = \frac{b_0}{a}\left(\frac{a}{r}\,\frac{\eta - 1}{\eta}\right)^{\eta} \tag{3'}$$

Assume an exogenous increase in demand for the product such that the new demand curve is as follows

$$Q^d = b_1\, p^{-\eta} \qquad b_1 = \mu b_0 \;,\; \mu > 1 \tag{1a}$$

Assume tht the producer can choose one of two alternative adjustments:

I: Conventional expansion, ΔK, which occurs at constant costs, r/a, but with a delay of ΘT, where T is the planning horizon and $1 > \Theta > 0$.

II: Output-increasing innovations via R outlays in research, development and engineering. The effect is assumed to be instantaneous and takes the form

$$Q^s = a\lambda(R)K_0$$

$$\lambda(R) > 1 \;,\quad \lambda'(R) > 0 \;,\quad \lambda''(R) < 0 \tag{1b}$$

The firm will decide on action I or II according to whether Π_I is greater or smaller than Π_{II} , where Π_i is the maximum profits during T attainable through action i .

Conventional Expansion

The expression for Π_I is as follows:

$$\Pi_I = aK_0\left[\left(\frac{b_1}{aK_0}\right)^{1/\eta} - \frac{r}{a}\right]\Theta T + a(K_0 + \Delta K_0)\left[\left(\frac{b_1}{a(K_0 + \Delta K_0)}\right)^{1/\eta} - \frac{r}{a}\right](1 - \Theta)T$$ [1]

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[1] From (2) we can see that $(b_1/aK_0)^{1/\eta}$ is the price of the product during ΘT while $[b_1/a(K_0 + \Delta K_0)]^{1/\eta}$ is the price during $(1 - \Theta)T$ (i.e., after the expansion took place).

where from (1b) and the form of optimum conditions (3), (3') we know that the optimum expansion ΔK_0 should satisfy

$$(K_0 + \Delta K_0) = \frac{b_1}{a}\left(\frac{a}{r}\,\frac{\eta - 1}{\eta}\right)^{\eta} \qquad (3'')^2$$

Introducing (3") into Π_I and substituting b_1 for μb_0 leads to:

$$\Pi_I = \frac{b_1}{\eta}\left(\frac{a}{r}\,\frac{\eta - 1}{\eta}\right)^{\eta-1} T\{\mu - \Theta[(\eta + \mu) - (1 + \eta\mu^{1/\eta})]\} \qquad {}^3(5)$$

Thus, the profits obtained from optimum conventional expansion under a bottleneck are expressed in terms of the parameters of the model: the demand shift factor, μ, the delay factor, Θ, etc.

Output-Increasing Innovations

Unlike the previous case, the optimum R^* and hence Π_{II} cannot be solved for explicitly in terms of the parameters of the model. This would require a further (and possibly undesirable) specification of the $\lambda(R)$ function. Instead of this we will aim at determining the ranges of $[\lambda(R^*), R^*]$ which are consistent with a bottleneck inducing output-increasing innovations even when unit costs of the increased output are higher under this action than under conventional expansion.[4]

[2] It follows from (3") and (3') that $\Delta K_0/K_0 = \mu - 1$.

[3] Since $\Pi_{I\,\theta=0} > \Pi_{I\,\theta>0}$ when $\mu, \eta > 1$, (5) together with $\mu, \eta > 1$ imply that $(\eta + \mu - 1) - \eta\mu^{1/\eta} > 0$.

[4] The first-order conditions of $\max_R Q(P - C)$ with action II give us:

$$\frac{\lambda'(R^*)}{\lambda(R^*)^{1/\eta}} = \frac{\eta}{(\mu - 1)\mu^{1/\eta} b_0 \left(\frac{a}{r}\,\frac{\eta - 1}{\eta}\right)^{\eta-1}}$$

A meaningful comparison of Π_I and Π_{II} would require a specification of $\lambda(R)$ which is both sufficiently appealing and simple enough so that R^* would be expressable in terms of the parameters of the model.

Total revenue, QpT, minus total cost, (rK T + R), under II can be written as follows [following (1b) and (2)]:

$$Ta\lambda(R)K_0\left[\left(\frac{b_1}{a\lambda(R)K_0}\right)^{1/\eta} - \frac{rK_0}{a\lambda(R)K_0}\right] - R = (aK_0)\mu^{1/\eta}\left(\frac{b_0}{aK_0}\right)^{1/\eta}\lambda(R)^{1-1/\eta}\,T - rK_0 - R$$

From (3) and (3'), and after writing R* instead of R, we get:

$$\Pi_{II} = \mu^{1/\eta}\, b_0\left(\frac{a}{r}\,\frac{\eta-1}{\eta}\right)^{\eta-1}\lambda(R^*)^{1-\frac{1}{\eta}}\,T - \frac{r}{a}\, b_0\left(\frac{a}{r}\,\frac{\eta-1}{\eta}\right)^{\eta}\cdot T - R^* \qquad (6)$$

Bottleneck necessary: For $\Theta > 0$ to be a necessary condition for innovating in response to an exogenous increase in demand (or, alternately, that conventional expansion be more cost-efficient than capital stretching) we must have:

$$\underset{(\Theta=0)}{\Pi_I} > \Pi_{II}$$

From (5) and (6) and rearranging terms we get the condition

$$\lambda(R^*)^{1-1/\eta} < \bar{A}(\mu) + B.R^* \qquad (7)$$

where

$$\left.\begin{aligned} \bar{A}(\mu) &= \frac{\mu + \eta - 1}{\eta\mu^{1/\eta}} > 1 \\ B &= \frac{1}{b_0\mu.^{1/\eta}\left(\frac{a}{r}\,\frac{\eta-1}{\eta}\right)^{\eta-1}.T} \end{aligned}\right\} \qquad (8)$$

Equation (7) states that for conventional expansion to be preferable in the absence of a bottleneck ($\Theta = 0$),[5] there should be limits to the productivity of research resources.

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5 I.e., to be the least-cost solution.

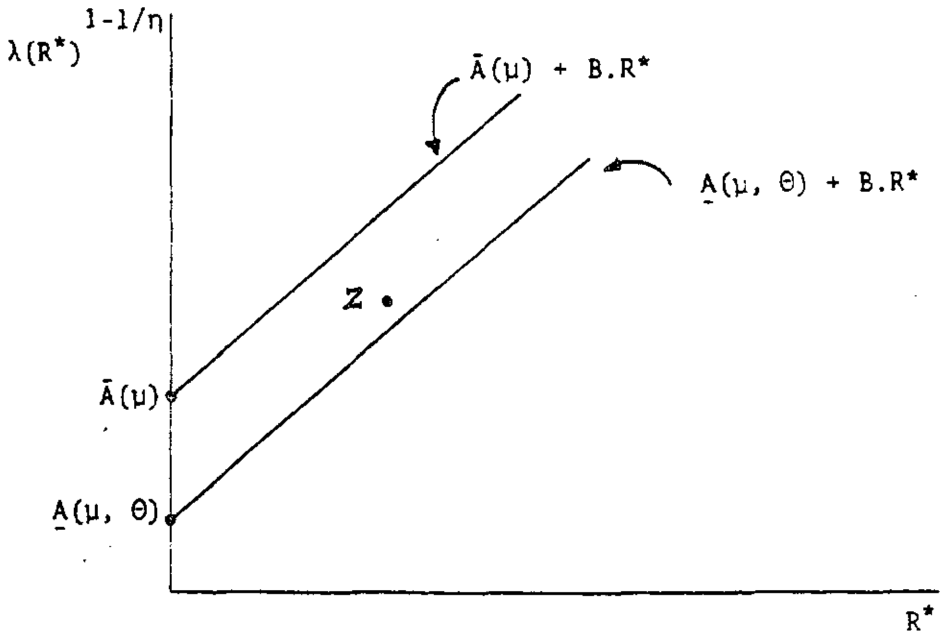

Figure 1

In particular, the $\lambda(R)$ function should be such that the $z = [\lambda(R^*)^{\eta-1/\eta}, R^*]$ combination which maximizes the profits from innovation should lie under the $\bar{A}(\mu) + B.R^*$ schedule of Figure 1. Any such combination above the schedule means that the higher exogenous demand will induce output-increasing innovations <u>even</u> in the absence of a bottleneck, i.e., bottleneck would not be a necessary condition.

<u>Bottleneck sufficient</u>: This requires that Θ be sufficiently high to compensate for the relatively higher unit costs of action II, i.e.,

$$\Pi_I > \underset{(\Theta>0)}{\Pi_{II}}$$

From (5), (6), and rearranging terms, this requires:

$$\lambda(R^*)^{\eta-1/\eta} > \underline{A}(\mu, \Theta) + B.R^* \qquad (7')$$

where

$$\underline{A}(\mu, \Theta) = \bar{A}(\mu) - \Theta \frac{(\mu + \eta) - (\eta\mu^{1/\eta} + 1)}{\eta\mu^{1/\eta}} < \bar{A}(\mu) \qquad (8')$$

Equation (7') implies that z should lie above the $\underline{A}(\mu, \Theta) + R^*B$ schedule of Figure 1 in order for capital-stretching innovations to be a preferred course of action in response to an exogenous increase in demand. This, in turn, implies that Θ, the delay in conventional expansion, should be sufficiently high.[6]

To sum up, any function $\lambda(R)$ yielding a z lying between both schedules of Figure 1 implies that output-increasing innovation will be elicited by the exogenous increase in demand, even though unit cost of the increased output exceeds the unit cost under conventional expansion. The existing delay in conventional expansion is therefore a necessary and sufficient condition for this kind of behaviour.

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[6] A rise in Θ will shift the $\underline{A}(\mu, \Theta) + R^*B$ schedule downward while leaving z unaffected.

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