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I. INTRODUCTION

INDUSTRIAL process innovations and their diffusion have been the subject of numerous theoretical and empirical investigations.[1] One recurrent problem for empirical work is posed by the ambiguity of the concept of a 'population of potential adopters' of an innovation. Yet, all judgments about the rate and likely economic effects of diffusion depend on a definition of *who* is a prospective adopter, at some point in time.

I have argued elsewhere [29] that at least part of this difficulty derives from the heavy intellectual debt which economic diffusion research owes to epidemiology. The formal models of the theory of contagion are based on the assumption that every member of a population, defined *a priori*, is susceptible to 'contact' with the item being diffused. But such an assumption is clearly inappropriate in the context of technological innovations and industrial adopters, for it sidesteps the question of the influence of existing production functions of firms on adoption decisions.[2]

This question takes on more than methodological importance at the point where analysts and policy-makers conclude that all firms (plants) in an industry are always candidates for the adoption of all process innovations, that the rapid diffusion of innovations is always optimal, and that, therefore, any firm that has not yet adopted an innovation is *ipso facto* 'laggard'.

If one sets to one side ideologically or politically motivated judgments of this type, one is still left with a puzzling persistence of the belief that all technological changes are economically attractive to all firms. Yet economists have adduced any number of reasons why non-adoption or a 'wait and see' strategy might be perfectly rational;[3] and the normative models of management science explicitly recognize that non-binding constraints in a production

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[1] See, for example, Blaug [6], Lynn [20], Mansfield [21], Ray [27], Gold *et al.* [16], Rosenberg [30], Nabseth and Ray [26].

[2] Nor can one extricate oneself from this difficulty by defining some 'equilibrium state' of diffusion, which itself is taken to be a function of a few specific variables. See, for example, Chow [11]. Criteria for adoption, and therefore prospective adopters, will frequently change over time. For a detailed discussion of relevant factors, see Gold [15].

[3] For an early exploration, see Brozen [7] and Salter [31]. Gold [15] draws on a broad range of empirical and behavioral observations to explain managerial receptiveness to innovations. Vaughan and Russell [36] make an interesting case for the possible divergence of privately and socially optimal diffusion paths.

system have zero shadow prices, i.e. that any changes in these constraints offer no economic improvement.

It may well be that the very concept of a production function, in the formal sense, does more to obscure the issue than to shed light on the real problems of innovation adoption.[4] Recognition of the *technological specificity* of production systems in an industry provides at least a partial remedy. It takes account of the fact that neither 'the' innovation nor the 'adopting units' frequently postulated in diffusion research are homogeneous, unchanging, entities. The characteristics of each plant are determined by more or less unique combinations of production stages, by capital equipment of different vintage, by input requirements, production flows, and output programs, as well as by technological capabilities that help to explain whether it will, at a given time, regard adoption as a potentially profitable move.[5] This claim of uniqueness does not imply that meaningful generalizations are impossible; rather, it suggests that such generalizations and categorizations can be derived only from an approach that breaks with the standard, albeit statistically convenient, notion of an industry as an assemblage of identical production units; and that the definition of meaningful populations of adopters is itself a matter of empirical investigation.

It is the purpose of the present paper to demonstrate the importance of technology-specific factors in the analysis of the diffusion of continuous casting, the most important recent innovation in steel-making. It will be shown that: (a) 'the innovation' must be thought of in terms of two, quite distinct, sub-techniques; and (b) the degree of vertical integration, the scale of operations, production flows, and output mix of plants aid in defining several adopting populations within the iron and steel industry. Incidentally, the findings also bring some additional evidence to bear on the problem of the industry's innovativeness, which has been the subject of a protracted controversy in the economic literature.[6]

II. CHARACTERISTICS OF THE INNOVATION[7]

The processing of the industry's key intermediate product, raw steel, traditionally involves a batch process. Molten steel (hot metal) is tapped from steelmaking furnaces into a ladle and then poured into ingot molds, in which it

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[4] For a detailed critique, see Brunner [8].

[5] The concept of technological specificity has its analog in the notion of the 'appropriateness' of technologies, which plays a major role in the literature on economic development.

[6] The controversy started with a predecessor innovation, the Basic Oxygen Furnace (BOF); see, for example, Adams and Dirlam [1], [2], McAdams [22], Rosegger [28], Dilley and McBride [12]. It continued along the same lines with continuous casting, as evidenced by Ault [4] and Huettner [18]. However, even the studies of Schenk [32] and Bundgaard-Nielsen [9], which make no judgments about innovative decisions, fail to deal with the innovation's differential characteristics.

[7] Material on the history of continuous casting and technical analyses can be found in United Nations [35], Gott [17], Morton *et al.* [25], Liestman [19], Willim [38], Domröse and Koch [13], Aylen [5].

is allowed to harden. The ingots are removed (stripped) from the molds, placed into inventory or transported directly to the so-called soaking pits, reheating furnaces whose function it is to bring the ingots to uniform temperature before they are rolled into the standard shapes: slabs and blooms (5–12 inches thick and 30–90 inches wide, in cross section), or billets and bars (of quadratic or rectangular cross-section, in the 4–8 inch range).

As Figure 1 shows, continuous casting by-passes these several steps. Molten steel is taken directly from the furnaces to a casting machine and drained from the transport ladles into the tundish (a refractory-lined funnel), through which the metal runs into the mold proper. There, the cooling process begins, and, with its outside hardened, the resulting strand of steel is withdrawn from the mold by a series of water-cooled rollers. Depending on machine design, this withdrawal may take place entirely in a vertical direction, the strand may be turned into a horizontal direction through a curved mold, or it may be bent in a wide radius after leaving the mold.[8] As it emerges from the machine, the steel is cut into workable lengths.

The throughput capacity of continuous casting machines is determined primarily by the following factors: the quantity of metal poured per casting cycle, the number of strands (which can vary from one to six), the cross-sectional dimensions of the strand being cast, and the withdrawal speed. With respect to these criteria, the operating characteristics and scale requirements differ vastly between billet casters on the one hand and slab casters on the other. As I shall argue below, these differences clearly demarcate continuous casting into two distinct techniques.

Even the simplified flow chart suggests that continuous casting should enjoy a considerable economic advantage over the traditional processing technique. In particular, this advantage is to be derived from the following:[9]

1. Savings in fixed-capital investment resulting from the elimination of several production steps, each of which requires heavy equipment. Estimates of these savings, in terms of investment costs per ton of capacity, range from 25 to 40%, as compared to the traditional technology.

2. Reductions in plant space of over 35%. This factor is judged to weigh heavily in older American plants, many of which are geographically constricted.

3. Reductions in energy costs of 30–75%, primarily through the elimination of the cooling-reheating cycles involved in the traditional technology.

4. Reductions in other operating costs through the elimination of labor and maintenance expenses connected with materials handling, in-plant transport, and ingot preparation.

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[8] As is frequently the case in the early stages of an innovation's diffusion, a standard design and configuration is emerging only through learning by the early adopters and by equipment suppliers (Rosenberg [30, p. 198]). In 1975, casting machines installed in American plants came from 16 different manufacturers, each of whom also modified his equipment over time.

[9] For sources of the quantitative estimates, see footnote 7, above.

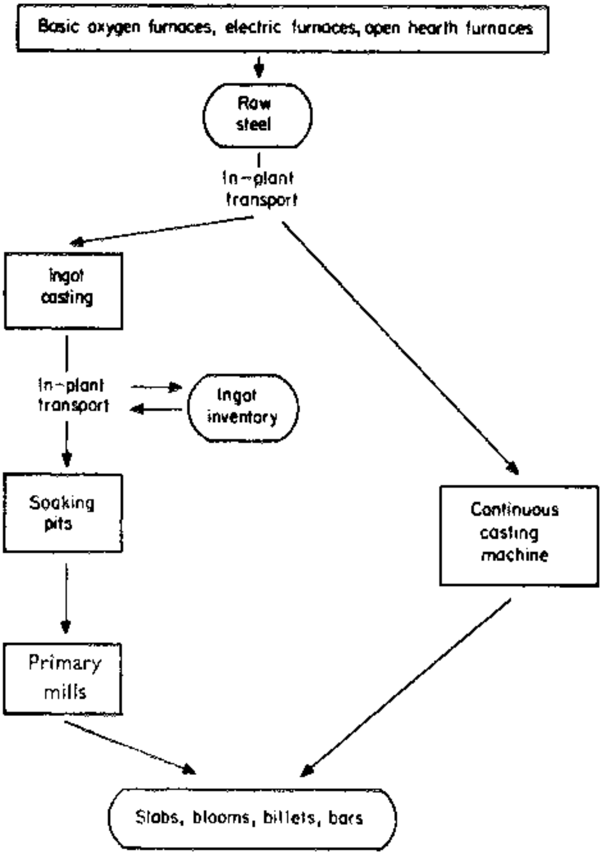

FIGURE 1. Traditional Process Technology vs. Continuous Casting

5. Improvements in yield, i.e. in the ratio of billet and slab output to raw steel input, from about 80 to 85% for the ingot route to 90–95% for continuous casting. Secondary benefits to be derived from yield improvements are: (a) a reduction in home scrap, which fits well especially with the BOF's reduced capability for utilizing scrap input;[10] and (b) a reduction in hot iron requirements in plants where blast furnace capacity is a bottleneck in the achievement of higher output rates.

6. In the case of slab casting, more efficient utilization of subsequent processing facilities. The full economic advantage of modern, 80–90 inch hot

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[10] The BOF, which accounts for the bulk of the raw steel output of the industry's integrated plants, requires scrap charges lower than 35% of total metallic input. By contrast, electric furnaces operate on 100% scrap charges; open hearth furnaces are completely flexible with respect to 'hot' and 'cold' metal input, albeit with important cost consequences. Thus, the steelmaking technique used, as well as the degree of backward integration, will have an important influence on the economic advantage of continuous casting in a given plant.

strip mills cannot be realized with the 'batch sizes' of even the largest technically feasible ingots. The ability to cut slabs of continuously cast steel to any desired length overcomes this limitation.

7. Improvements in the quality of the output. Two aspects are of special importance for cast slabs: (a) better surface quality makes for superior flat-rolled products and eliminates much of the cost of scarfing and other surface-repair operations; and (b) for metallurgical reasons, continuously cast steel has an advantage over ingot steel in certain final applications, such as the manufacture of deep-drawn cans.

Taken *in abstracto*, these economic benefits would appear to argue persuasively for the speedy adoption of the innovation. However, if one takes into account the problems of technological specificity in existing production systems, several observations are in order: first, the realization of the full range of advantages depends on continuous casting being a *replacement* investment, i.e. on the actual elimination of the unfavorable cost elements of ingot technology, or on the innovation's incorporation in a greenfield plant. As will be seen below, the scale and technical characteristics of the new technique are such that total replacement is an economically attractive option only in the case of billet casting, and there only for plants with a raw steel capacity of less than 600,000 tons per annum. At the present stage of the development of slab casting in large integrated plants, total replacement of ingot facilities is not considered an option; and, in the American setting, the question whether slab casting should be adopted as the sole technique in greenfield plants is still largely moot.[11]

Second, the adoption of continuous casting on an *incremental* basis, i.e. without abandonment of any of the existing ingot-route facilities, will not only negate several of the innovation's potential cost advantages but will lead to some cost increases, because of the need for duplication in the planning and co-ordination of production flows. Needless to say, this problem is more serious for large, integrated mills than for smaller-scale producers.

Third, gaining incremental capacity via the innovation will nevertheless prove attractive in all situations where increments are well below the minimum efficient size of traditional equipment.[12] Furthermore, learning with the new technique can then take place with the old facilities serving as a 'back-stop' in case of disruptions and breakdowns.[13]

Fourth, the realization of the innovation's economic advantages, even under these conditions, will depend on a number of technology-specific factors, among them primarily: the size of production runs of a particular cross-

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[11] In 1975 there existed only two integrated plants, world-wide, that relied entirely on continuous slab casting for the processing of their raw steel output.

[12] Therefore the judgment of one expert that '... [it] seems improbable that any new slabbing mills will ever be built in this country' (Stubbles [33]). The problem of efficient scale is less severe for billet mills.

[13] Indeed, 'getting one's feet wet' with the new technique was considered as important by many early adopters as were foreseeable economic advantages (McManus [24]).

section and metallurgical quality, which are determined by the plant's output mix; the 'fit' of the new technique into the existing plant's physical lay-out and operating practices; and the ability of operators to run the casting machine at levels approaching its rated capacity.[14]

Given these considerations, it is not surprising that identical *ex ante* judgments about the technical and economic potential of continuous casting would lead to differing decisions among firms in the iron and steel industry. It is possible to distinguish three sub-populations of potential adopters by drawing on the factors listed above and by recognizing the fundamental difference between billet casting and slab casting techniques. Estimates of installed capacity in these three segments are shown in Table I.

TABLE I

ESTIMATED TOTAL RAW-STEEL CAPACITY AND CONTINUOUS CASTING CAPACITY, 1975 (IN 1000 TONS)

	Capacity		
Segment	*Total raw steel*	*Billet casting*	*Slab casting*
Integrated carbon steel producers	150,000	3,400	10,000
Non-integrated (scrap-based) carbon steel producers	15,000	7,000	—
Specialty and alloy steel producers	11,000	600	4,600

Sources: Author's compilation from *Journal of Metals* (1973); *Iron and Steel Engineer* (1975); AISI (1976); *IISS Commentary* (1977).

The data show substantially different levels of adoption.[15] Billet casting has found the highest level of acceptance among the non-integrated producers of carbon steels, frequently referred to as 'mini-mills'. Its penetration into the industry's main segment is considerably lower, and its use by specialty producers negligible. On the other hand, slab casting installations could (theoretically) process over one-third of the specialty and alloy segment's raw steel output; in absolute terms, installed capacity in integrated carbon steel plants is largest, but this accounts for only a small portion of total processing requirements.

Figure 2 shows the time patterns of adoption for billet casting and slab casting in the several segments of the industry. It forms the basis for our subsequent exploration of the differences in diffusion rates. Here it is necessary only to make one general observation: it would obviously be very misleading to measure the innovation's acceptance by the number of adopters, without regard to the size of installations and their relative economic significance to

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[14] As is customary, published estimates of the innovation's superiority assumed ideal operating conditions and full capacity utilization; these assumptions are rarely met during the early life of a major innovation, where 'early' may mean as many as six to ten years.

[15] It must be emphasized that the statistics reflect *rated capacities* of continuous casting installations. Data on the proportion of actual output accounted for by the innovation are not available. Our research suggests, however, that it was generally well below these rated capacities during the period under review.

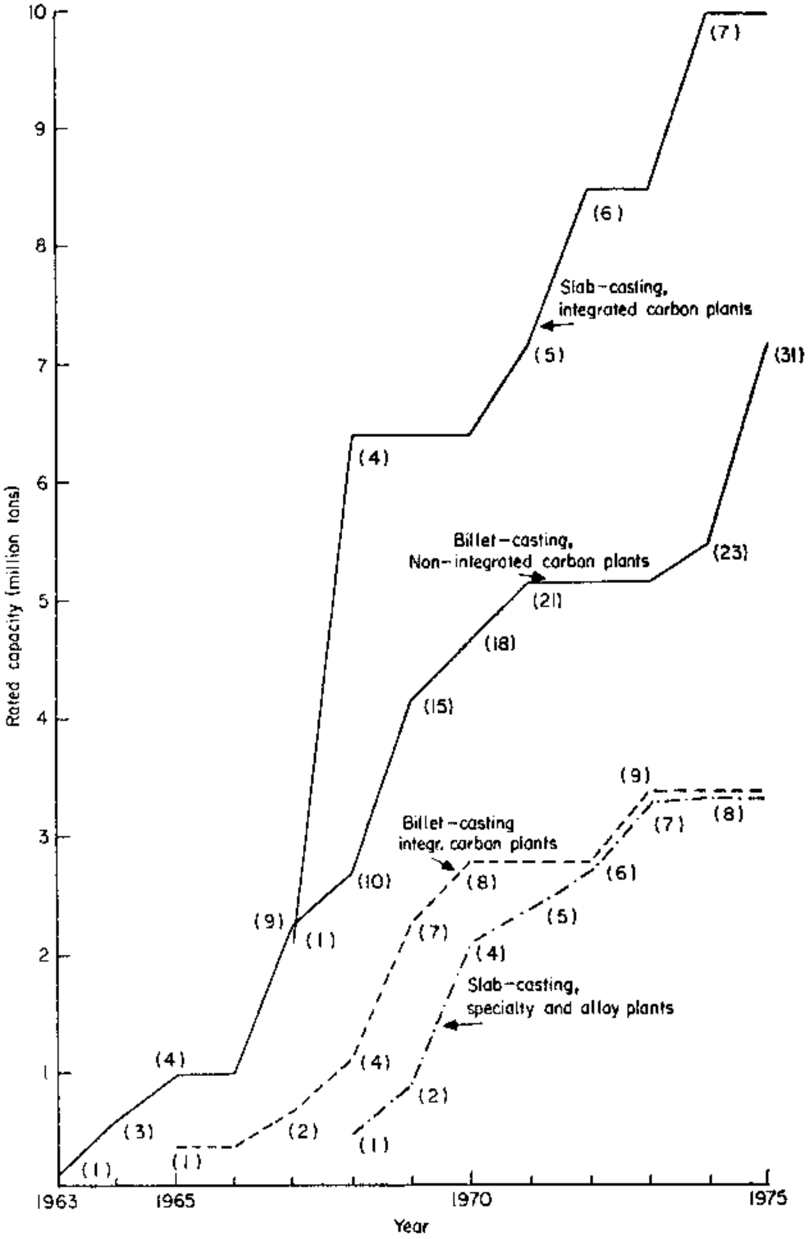

FIGURE 2. Installed Continuous-casting Capacity, by Types of Casting and Plants, 1963–75 (number of installations in parentheses)

these adopters; therefore, both the cumulative installed capacities and the number of installations are given in the figure.

III. THE DIFFUSION OF BILLET CASTING

A. *Background*

Commercial billet-casting facilities were first started up in Europe, in the early 1950s.[16] These were very small installations, typically in conjunction with low-output alloy and specialty steel plants. A gradual scaling-up occurred over the next decade, with annual machine capacities growing from approximately 15,000 tons to over 100,000 tons. At this point, the innovation assumed economic interest even for carbon-steel producers.

Once the initial technical problems had been solved, the quality of continuously cast billets and bars proved itself at least equal to that of the traditional technology. Experience with respect to the innovation's cost advantage varied greatly, depending on conditions; nevertheless, the steady accumulation of performance information no doubt contributed to a widening of the circle of potential adopters. At the same time, the basic design of casting machines underwent continual modification.

Rapid, world-wide diffusion did not begin until the early 1960s, although national adoption rates varied considerably.[17]

B. *Diffusion Among Non-integrated Producers*

Non-integrated plants are those not having iron-melting (blast furnace) facilities. Instead they rely on, mostly regional, scrap supplies for their raw materials input and melt these down in electric steel-making furnaces. These typically single-plant firms are widely dispersed geographically, serving their surrounding market areas with common carbon-steel products.[18] The popular designation, mini-mills, is appropriate, since even the largest of them are only approximately one-third the size of the smallest economically feasible integrated plants.

By the iron and steel industry's general standards for the adoption of major innovations, diffusion of billet casting among these producers was very rapid.[19] By 1975, 31 of 54 plants in the segment had continuous casting installations, and these accounted for almost half of raw steel capacity. Three sets of factors largely explain the ready acceptance of the innovation: the relative ease with which the operating problems of billet casting were solved by equipment suppliers and early users; the good balance between the feasible range of electric-furnace and casting capacities; and the plants' very restricted output program.

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[16] A complete listing of early facilities can be found in United Nations [35].

[17] For international comparisons of rates, cf. Schenk [32] and Aylen [5].

[18] On the economics of small-scale carbon steel-making in these plants, see McManus [23].

[19] Comparative data on the diffusion of major innovations in iron and steel can be found in Gold *et al* [16].

The experience of early adopters rather quickly established the main outlines of sound operating procedures, although it would be an exaggeration to say that these had become standardized.[20] But, since the products made by non-integrated producers fall into a very narrow range, experience did prove to be readily transferable.[21]

The compatibility of efficient electric furnace scales and billet casting capacities is demonstrated in Table II. Thus, these producers could in many instances match up initial plant sizes and expansions without any of the imbalances that frequently mark the introduction of a major process innovation into an existing production system. In this connection, it is significant that 30% of the non-adopting plants are in the capacity range above 300,000 tons annually, while only 15% of the adopters fall into this size class, and the largest of these latter does not rely exclusively on continuous casting. Finally, it should also be observed that the batch sizes of output resulting from electric furnace steel-making, typically 20–50 tons, are well attuned to to the requirements of billet casting.

TABLE II

SIZE DISTRIBUTION OF STEELMAKING AND CONTINUOUS CASTING CAPACITIES, NON-INTEGRATED CARBON STEEL PRODUCERS, 1975

	Percentage of steelmaking facilities		
Annual capacity (1000 tons)	*Non-adopters (n=23)*	*Adopters (n=31)*	*Percentage of continuous casting facilities*
100 or less	22	22	15
101–200	39	44	57
201–300	9	19	11
301–400	9	7	6
401–500	12	7	11
Over 500	9	1	—
	100	100	100

Source: Author's calculations, from *Iron and Steel Engineer* (1975).

The production program of the typical non-integrated plant covers a very narrow range: concrete reinforcing bars, light structural steels, rounds and wire rods account for the bulk of the segment's output. This means that continuous casting machines are generally designed to produce a single, or at most two or three, cross-sectional dimensions in large quantities. At the same time, there is sufficient variety in machine design to help these plants avoid the penalties of what might otherwise appear to be inefficiently small scales of operation.

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[20] For the typical problems of early adopters, see for example Williamson [37].

[21] The reliability of billet casting technique is best indicated by the fact that, by 1975, the great majority of these plants had abandoned all ingot facilities, or retained them only on a stand-by basis.

C. *Adoption by Integrated Producers*

Integrated iron and steel plants confront technical and economic conditions quite different from those faced by small, scrap-based producers. First and foremost, small cross-section products here constitute but a portion of a large and variegated mix of outputs. Although their shares in this mix differ from plant to plant, they are typically much smaller than those of flat-rolled products.

Furthermore, the economically efficient scale of BOF and open-hearth steel melting facilities (the prime suppliers of hot metal in integrated plants) is such that the processing of characteristic batch sizes in billet-casting machines alone would not only pose serious operating problems, but would be economically unattractive.[22] There is, therefore, no question of a balance between steelmaking and casting capacities, and only large casting machines can be considered a genuine alternative to the traditional technology. None of the installations in integrated plants has an annual capacity of less than 200,000 tons, whereas almost three-fourths of the casting facilities in non-integrated plants are smaller than that.

In all but two cases, both small, specialized plants in remote locations, investment in continuous billet casters was of the incremental type, their processing potential ranging from 9 to 33% of annual raw steel output. The retention of traditional technology was dictated not just by the size limitations of billet casters; given the need for a wider range of products, the co-existence of both types of facilities assured plants of greater flexibility. Large production runs of constant dimension can be accommodated most economically on the casters, whereas smaller runs are handled efficiently via the ingot route.

Finally, the quality requirements for casting output tend to be higher in integrated plants than in non-integrated ones. This is true particularly in those situations where the large producers have dropped from their output programs as uneconomical precisely those low-grade products in which the scrap-based firms have specialized.

In light of these considerations, it is clear that continuous billet casting had to meet different, and generally more stringent, criteria for adoption in the industry's integrated segment than in the non-integrated segment. At the same time, the economic advantages of the innovation obviously proved more persuasive to the latter. In this connection it is important to recall as well that investment in billet casting had to compete with a wide range of other investment opportunities for the large firms, and that these opportunities might easily rank higher in managerial evaluations.

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[22] Thus, for example, it has been estimated that the processing of 200-ton heats of molten steel from a two-vessel BOF shop into 6 × 6 inch billets would require a 12-strand casting machine (Stubbles [33]). Six-strand machines were the largest in existence in 1975.

IV. THE DIFFUSION OF SLAB CASTING

A. *Background*

The casting of slabs and blooms posed, and continues to pose, many more technical and operating problems than billet casting. Although large-scale experiments[23] with the technique had been carried on in Western Europe in the middle and late 1950s, these proved of little initial interest to American firms. Very slow casting rates and persistent difficulties with the surface quality of slabs suggested that the innovation needed considerable development before it could be considered for adoption. Starting in the early 1960s, United States integrated firms, individually and in co-operative projects, carried on a number of pilot operations. By the middle of the decade, these experiments, as well as the technical (if not economic) success of several installations abroad, had created a climate in which decisions on the possible adoption of slab casting had to be confronted seriously.

At the same time it was apparent that all design and operating problems had not been solved, and that fitting the new process into the existing production system of large, integrated plants would involve considerable uncertainty on the technical and the economic front.[24] However, the main motive for adoption was the recognition that this uncertainty could be removed only through learning in full-scale, commercial operations.[25] Given the smaller capacities of specialty producers, and their reliance on electric-furnace steel-melting (with its smaller batches of output), scaling-up problems were somewhat less severe than in the large carbon-steel plants.

B. *The Pattern of Adoption*

The adoption pattern for slab casting shown in Figure 2 can be examined in greater detail with the help of the installation data of Table III. The differentiation between carbon and specialty steel production becomes readily apparent from these statistics. In plants devoted to the manufacture of specialty and alloy steels, we find slab casting capacities in the range from 150,000 to 600,000 tons; on average, these plants are comparable in size to the larger billet-casting facilities.[26]

By contrast, the slab casters in carbon-steel plants are substantially larger and yet they generally meet only a fraction of the total raw steel processing requirements of these plants. Given the batch-size and total output charac-

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[23] 'Large-scale' here means annual target capacities of 250,000–300,000 tons at most, still economically unattractive to American integrated producers.

[24] A listing of the technical difficulties encountered in our survey of installations would go beyond the scope of this paper. Some indication of these difficulties is given by the fact that a 30% operating availability of machines is regarded as quite satisfactory.

[25] A typical example may illustrate the length and costliness of this learning process: in the case of a large carbon-steel slab caster, operating costs per ton of output during the year of start-up were 137% higher than for the traditional technology; in the third year of operations, the cost disadvantage was still 27%.

[26] Four of the eight specialty and alloy steel plants are properties of large integrated firms, although located away from their carbon-steel facilities.

TABLE III

RATED CAPACITIES OF CONTINUOUS SLAB CASTING PLANTS, 1967–75

Year of start-up	*Rated capacity (1000 tons)*		*Continuous casting capacity as percentage of raw steel capacity*	*Source of raw steel*[b]
	Carbon-steel plants	*Specialty and alloy plants*		
1967	2100		25	BOF
1968	2500		92	BOF
	1500		40	BOF
		450	95	EF
	250[a]		100	OH
1969		400	n.a.	EF
1970		600	45	EF
		600	100	EF
1971	800		40	BOF
		300	30	EF
1972		330	50	EF
	1300		30	BOF
1973		600	100	EF
1974	1500		30	BOF
		150	50	EF
1975	—	—		

[a] This is an installation in a small carbon-steel plant serving a regional market. Its reliance on the open hearth process for raw steel suggests its exceptional character among the adopters of slab casting.

[b] BOF = Basic Oxygen Furnace; EF = Electric Furnace; OH = Open Hearth Furnace.

Source: Author's adaptation from *Journal of Metals* (October 1973).

teristics of the Basic Oxygen Process, the economically efficient operation of slab casting machines in large integrated plants depends on their ability to accommodate, with a minimum of planned or unforeseen disruptions, the flow of hot metal from the steel-melting segment.[27]

It is reflective of the innovation's technical development, in terms of its feasible scale and reliability in operation, that none of the carbon-steel plants relies entirely on continuous slab casting and that few of the ingot and slabbing-mill facilities have been placed on 'stand-by' or abandoned. The incremental character of the new technique deserves special emphasis. Justification for the investment had to be found either in terms of the need for additional capacity or in terms of specific product-quality requirements, or—with a broader perspective—in terms of the need to become closely familiar with 'the technology of the future'.[28] Judgments about the timeliness of these forays into new technological territory must also be informed by the knowledge that the initial cost of a slab-casting machine of approximately one million tons annual capacity lay in the range of $50–70 million for the early adopters; it has risen substantially since then.

The single most important requisite for the realization of the innovation's latent economic advantage (whatever the original motives for adoption)

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[27] Planned disruptions are those resulting from the deliberate scheduling of hot metal for traditional processing, because of repairs or adjustments on the casting machine.

[28] In our survey of early adopters, we found none that justified the investment on the basis of expected cost savings. See also McManus [22].

turned out to be the practice of *sequence casting*, i.e. the processing of several heats of molten steel without interruption. A target sequence of three to four heats (800–1200 tons) is considered realistic for day-in, day-out commercial operations, although much larger sequences have been achieved under carefully prepared 'record-setting' conditions.[29] Yet, early installations have had to pay a price for pioneering: they have found it difficult to meet even this target, since the machines of the late 1960s were not really designed for sequence casting, which was then regarded as a rather remote future possibility. In this respect at least, a wait-and-see strategy clearly paid off.

V. SUMMARY AND CONCLUSIONS

This paper has argued that the question of *who* the potential adopters of a major industrial innovation are, at any given time, is a matter for empirical investigation and not one of some *a priori* definition of an 'industry'. It was suggested that the concept of technological specificity in existing plants provides a useful guide for the categorization of 'populations' of potential adopters. Decision-makers will, after all, evaluate the expected cost advantages of a new vs. an old technique within the context of their production set-up, and not in terms of some abstract economic criteria.

In applying this concept to the diffusion of continuous casting in the American iron and steel industry, it was found that (a) the innovation must be considered as consisting of two sub-techniques with quite distinct technical and economic implications—billet casting and slab casting; and (b) three distinct industry segments must be identified if one wishes to explain the rate of adoption. These segments are characterized by different scales of operation, by different degrees of vertical integration, and by different production programs, with respect to both the quality and the range of products manufactured.

In the case of billet casting, these factors were sufficient to explain the rapid adoption in one segment and the slower in another. In the case of slab casting, two additional factors—market conditions which justified capacity expansion on an incremental basis, and the continuing need for learning and therefore the slow emergence of the innovation's economic advantage—played a major role in adoption decisions. To the extent that an acceleration of diffusion rates is supposed to follow the reduction of initial uncertainty about a new technique's performance (Mansfield [21, p. 119]) we may judge that the experience with slab casting of carbon steels has not yet provided potential adopters with sufficiently unequivocal information to hasten adoption decisions, especially since the industry has to confront persistent capital shortages.

Ultimately, judgments about the speed of diffusion, whether made by

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[29] A record sequence of over 100 heats was achieved in Japan, according to an American expert.

champions or by attackers of an industry's behavior, must be tempered not only by the considerations adduced in the present paper, but also by a more fundamental empirical fact: in the case of major innovations in iron and steel, it is impossible to draw any conclusions about their eventual success from their diffusion rates during the first 15 years after commercial introduction. When one compares the spread of billet casting and slab casting in the American industry's relevant segments with the pattern found for 14 other innovations (Gold *et al.* [16]), one observes rates entirely within the range of historical experience. Thus, the frequently expressed belief that continuous casting will eventually gain an absolute technical and economic advantage over all other processing techniques still awaits substantiation by experience in the United States setting.

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