

TECHNOLOGY AND OLIVER WILLIAMSON'S TRANSACTION COST ECONOMICS

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Received November 1986, final version received August 1987

Oliver Williamson has greatly contributed to refining neoclassical economics by incorporating transaction costs and internal organization; yet, his new institutional economics too easily dismisses the role of technology. In doing so, he has replaced the determinism of technological production efficiencies with the determinism of transaction cost efficiencies. A review shows that Williamson's new institutionalism has evolved through three stages in terms of the focus of his analysis and his views of transactions. Throughout this evolution, however, his proposed solutions to organizational failures have actually continued to rely heavily upon technology.

1. Introduction

Oliver Williamson has, over the past decade, created a 'new economics' which has revived an old, yet neglected, economic interest in contracting and transaction costs (1975, 1979, 1981, 1985). The strength of Williamson's analysis has been his consideration of transaction costs. In doing so, however, he has overstated the case against technology as a factor explaining organizational forms. Indeed, he excludes almost all technological considerations. The result is to replace technological determinism with transaction cost determinism.

In the first half of this paper I describe the changes in Williamson's new institutionalism as it has evolved over the past decade. By focussing on his discussion of transaction costs and technology, I identify three distinct stages in the development of his assumptions, approaches, and conclusions. These stages are associated with the concepts of organizational failure, transaction costs, and asset specificity.

In his initial writings, Williamson focussed on the dynamics between the environmental and human factors in writing and enforcing contracts. These dynamics created transaction cost difficulties and brought about organizational failures. Williamson devoted little attention to specifying what he meant by transactions and transaction costs, but, rather concentrated on showing how the shift to internal organization alleviated market-related failures.

In his second stage, Williamson omitted an analysis of environmental

factors and, instead, focussed on the transactions themselves. Although he continued to struggle with a definition of transactions, he introduced a set of factors around which such a definition could be created. He began to specify his organizational analysis by introducing the concept of alternative governance structures. Finally, he formally integrated his new transaction cost economics with neoclassical theory by including the alternative governance structure as another factor in the traditional production function whose costs need be minimized to maximize the returns from output.

Most recently, Williamson has focussed his attention on efficient governance structures. He introduced asset specificity as the transactional dimension of special interest. Yet asset specificity is, in fact, a redefined version of 'information impactedness' – a concept he abandoned many years before. It actually explains better what he left vague in his initial work, i.e., the two-way dependencies of transactions.

In the second half of this paper, I show that despite Williamson's discounting of technological considerations, his proposed solutions to the organizational failures which transaction costs bring about actually rely heavily upon technology. I propose that a more analytically and historically complete understanding of technology and transaction costs occurs when we examine their historically-specific interrelationship rather than give pre-eminence to either one.

2. Internal organizational failures

In the initial presentation of his new institutionalism, Williamson focussed on the transaction as the key element of economics and, in particular, on the dynamics between environmental and human factors in conducting transactions. These dynamics would explain why transactions that might otherwise be handled in the market through contractual agreements are shifted into hierarchical arrangements, i.e., why administratively governed firms are created. In *Markets and Hierarchies* (the culmination of a series of articles in the early 1970s), Williamson's goal was to provide a 'better understanding of the origins and functions of various firm and market structures' (1975, p. 1).

According to Williamson, this shift from market to firm was caused by market failures. These failures were transaction costs which could 'be attenuated by substituting internal organization for market exchange' (1981, p. 114). Williamson, in this earlier work, did not pay much attention to specifying what he meant by either 'transactions or transaction costs'. Instead he relied on other economists and economic traditions to define the terms of his new economics. In particular, he traced the origins of his economics to that of John R. Commons and Ronald H. Coase (1975, p. 254).

It was Commons who focussed on the transaction as the economic unit of investigation, but it was Coase who directly asked why the firm need exist at

all. He looked to transaction costs for his answer. Through Coase we receive Williamson's definition of these costs. Williamson's criticism of what he otherwise calls Coase's 'uncommonly insightful treatment' is that it fails to go far enough so that economists can systematically 'assess the efficacy of completing transactions between firms and markets'. Thus Williamson distinguished his work from his predecessors by his attention to both environmental and human factors and how they influence economic organization. He argued that environmental factors of uncertainty and small-numbers bargaining join together with the human factors of opportunism and bounded rationality which precipitates the move from markets to hierarchies (1975, pp. 4, 7).

Williamson initially provided a limited definition of transaction costs as (a) the costs of discovering relevant market prices and (b) the costs of negotiating and completing contracts. With this definition he used his markets and hierarchies approach to develop his 'organizational failures framework'. This explained how it is that transaction costs arise and why internal organization has significant advantages over the market with these increasing costs.

In developing this framework he also developed a complex vocabulary to argue that the joining of two environmental factors¹ and two human factors² into distinct arrangements leads to transaction cost difficulties and, in turn, organizational failures when there are recurrent contracting situations. He identified three combinations of factors which lead to organizational failures, each of which could be overcome with internal organization – hierarchies rather than markets.

In the first combination, when bounded rationality is linked with complexity/uncertainty, bargainers are unable to define complete recurring, contractual agreements because neither all alternative futures nor their corresponding prices can be determined (1975, p. 25). The second failure arises when opportunism combines with a small-numbers exchange. Although competitive behavior can overcome individual opportunistic incli-

¹The first, complexity/uncertainty, is the inability (because of extremely high costs) or even the impossibility of developing a decision tree which allows all the possibilities of a contractual relationship to be described. This failure results from the large number of alternative paths, the lack of directional aids, and the problem of estimating consequences. The second, small-numbers exchange, i.e., two-party or bilateral bargaining, occurs either from the outset (*ex ante*) or when contracts are renewed (*ex post*).

²The first, bounded rationality, limits the 'powers of individuals to receive, store, retrieve, and process information without error' and limits individuals' abilities to 'articulate their knowledge or feelings by the use of words, numbers, or graphics in ways which permit them to be understood by others' (1975, pp. 21–22). The second, opportunism, is a combination of self-interest with either guile, or 'strategic' manipulation of information, or misrepresentation of intentions. This does not include advantages known by all parties at the outset of a contract, but rather is one party's 'selective or distorted information disclosure' or 'self-disbelieved promises regarding future conduct'.

nations when there are large numbers of bidders, Williamson argues that recurrent contracting leads to a small-number exchange during contract renewal. This small-number exchange arises because 'winners of original bids subsequently enjoy non-trivial cost advantages over non-winners' and obtain 'first-mover advantages' (1975, pp. 29–30).

A third failure, 'information impactedness', arises when uncertainty combines with opportunism. This condition exists when the underlying circumstances relevant to the transaction, or related set of transactions, are known to one or more parties, but cannot be costlessly discerned by or displayed for others. It occurs particularly where there is a small-numbers exchange. This information is 'impacted' either for opportunistic reasons – original winners refuse to disclose it – or because of bounded rationality – they may be unable to disclose it despite their best efforts to do so. When this condition exists, small-numbers bargaining situations emerge where large-numbers bargaining may have prevailed at the initial contract stage (1975, pp. 35–36).

3. Transaction cost economics

In his seminal 1979 and 1981 articles, Williamson respecified his new economics. His previous 'organizational failures framework' was an integrated model of environmental and human factors, which when joined together, created significant transaction costs. In this second stage, Williamson's model has evolved into a 'transaction cost economics' which omits the concept of environmental factors and is more concerned with the nature of transactions themselves.

As with his earlier work, Williamson maintained that changing the internal organization of the firm (i.e., from market to hierarchy) has the purpose and effect of economizing on transaction costs. Yet, he introduced the notion of 'alternative governance structures' to refer to the 'explicit or implicit contractual framework within which a transaction is located', i.e., markets, firms, or mixed modes (1981, p. 1544). By including this organizational factor, Williamson apparently separated his work from traditional neoclassical economics which attributes a simple profit maximization objective to the firm.

Yet, Williamson did not separate himself, but rather only added an organizational factor to the traditional production function. He clearly stated the organization problem in traditional economic terms: 'assess alternative governance structures in terms of their capacities to economize on bounded rationality while simultaneously safeguarding transactions against opportunism. This is not inconsistent with the imperative "maximize profits!", but it focuses attention somewhat differently' (1981, p. 1546).

As if to emphasize the neoclassical heritage of his work, he redefined the

firm as a production function with an organizational or governance structure included as a factor. Thus the selection of the governance structure became a mathematical optimizing problem: ...for a given organization form (f), choose output (Q) and [product] design (D) so as to maximize:

$$\#(Q, D, f) = P(Q, D) \times Q - C_f(Q, D; S) - G_f(Q, D),$$

where $\#$ denotes profit, $P(Q, D)$ is the demand curve, S denotes combinatorial economies of scope, C_f and G_f are the production costs and governance (transaction) costs of mode f (1981, p. 1551, n. 24).

Presented in this way, the trade-offs between production costs and transaction costs are made explicit. Because of these trade-offs, Williamson devoted more attention to the nature of the transactions themselves. He 'dimensionalized' transactions by identifying a set of transaction 'attributes' which are of special interest to the economics of organization.

Many economists, even those sympathetic to the approach, have complained about the ubiquity of transaction-cost explanations. Williamson, himself, related Stanley Fischer's charge that 'transaction costs have a well-deserved bad name as a theoretical device... [partly] because there is a suspicion that almost anything can be rationalized, by involving suitably specified transaction costs' (1979, p. 233).

In response, Williamson conceded that although 'the new institutional economics is preoccupied with the origins, incidence, and ramifications of transaction costs [it is a] concept want[ing] for definition' (1979, p. 233). In 1979, Williamson failed to find a satisfactory definition but identified a consensus of factors around which a definition could be created: '(1) opportunism is a central concept in the study of transaction costs; (2) opportunism is especially important for economic activity that involves transaction-specific investments in human and physical capital; (3) the efficient processing of information is an important and related concept; and (4) the assessment of transaction costs is a comparative institutional undertaking. Beyond these general propositions, a consensus on transaction costs is lacking' (1979, p. 234).

It is not coincidental that this 'consensus' of factors includes all of those which Williamson, himself, presents in his new economics. Williamson had previously taken his definition of transaction costs from Coase and had only added Kenneth Arrow's simple dictum that transaction costs can be thought of as 'costs of running the economic system'. Williamson found Arrow's approach easy to convert into contractual terms: 'Each feasible mode of conducting relations between technologically separable entities can be examined with respect to the ex ante costs of negotiating and writing, as well as

the ex post costs of executing, policing, and, when disputes arise, remedying the (explicit or implicit) contract that joins them (1981, p. 1544).

4. Transactional attributes and asset specificity

In his most recent work, Williamson puts the views of Coase and Arrow into his own terms and characterizes transaction costs as the 'economic equivalent of friction in physical systems' (1985, p. 19). In more descriptive terms he writes that a 'transaction occurs when a good or service is transferred across a technologically separable interface. One stage of processing or assembly activity terminates, and another begins. A well-working interface, like a well-working machine, is one where these transfers occur smoothly. In mechanical systems, we look for frictions: Do the gears mesh? Are the parts lubricated? Is there needless slippage or other loss of energy? The economic counterpart of friction is transaction cost: Do the parties to the exchange operate harmoniously, or are there frequent misunderstandings and conflicts that lead to delays, breakdowns, and other malfunctions? Transaction-cost analysis supplants the usual preoccupation with technology and steady-state production (or distribution) expenses, with an examination of the comparative costs of planning, adapting, and monitoring task completion under alternative governance structures' (1982, p. 104).

With this more complete description of transaction costs, Williamson now focuses on the 'attributes' of transactions (what he calls 'dimensionalizing') and this represents the key addition to his new economics in the 1980s. These attributes are (1) the 'frequency' with which transactions recur, (2) the 'uncertainty' to which transactions are subject, and (3) the degree to which transactions are supported by durable, 'transaction-specific investments' (1981, p. 1546).

Focusing on these three attributes allows the concept of transactions to be useful in identifying efficient governance structures (which was the primary fault Williamson found with Coase's work). Yet, only the third attribute, asset specificity, is of importance to the new economics. This is because Williamson treats the other two attributes as 'givens' in the model. For Williamson, the important issues revolve around recurring or frequent and entail an 'intermediate degree' of uncertainty. Thus, Williamson concludes 'asset specificity is the transactional dimension of special interest' (1981, p. 1548).

This new element in the model, asset specificity, means an asset is less transferable to other uses and users. It can arise in three different ways: (1) 'site specificity so as to economize on inventory and transportation expenses'; (2) 'physical asset specificity, as where specialized dies are required to produce a component'; or (3) 'human asset specificity that arises in a learning-by-doing fashion' (1981, p. 1546).

On close examination, this 'new' element is, in fact, a redefined version of 'information impactedness' which Williamson introduced in *Markets and Hierarchies*. Information impactedness resulted from the joining together of opportunism and uncertainty which led to a small-numbers exchange. Uncertainty and small-numbers exchange were the environmental factors in his earlier model. Williamson no longer refers to his 'organizational failures framework', nor to environmental factors. Yet he retains the factors in his new model but under other names. Uncertainty is now a transactional attribute and is assumed to exist to an 'intermediate degree'. Small-numbers exchange now results from asset specificity which is able to transform an initial large-number bidding situation into a bilateral trading relation.

By reworking his model and introducing 'asset specificity', Williamson better explains what 'information impactedness' had left vague. In particular, asset specificity better reveals the two-way dependency of these transactions. The seller and buyer become 'locked into' the transaction as the asset becomes more specific: at contract renewal, buyers do not have immediately available competitive suppliers and sellers can find few buyers for the specialized asset.

The issue of interest here is not whether there are large fixed investments (although this can also be important), but how specialized are the investments. If an asset supplier can easily turn to other buyers or if other sellers are available to the buyer, then there are few transactional risks. On the other hand, transactional problems arise when assets become more specific or more fully dedicated to the specific needs of the buyer (the firm). Williamson refers to transactions which involve highly specific assets as 'idiosyncratic'. As indicated earlier, this specificity can arise because of its site, its physical qualities, or its human qualities. It is the latter, human asset specificity, which particularly interests Williamson because it involves the personal relationship between the buyer and seller or the owner and worker and is exemplified by specialized training and learning-by-doing economies in production (1979, p. 240).

Williamson concludes, 'where asset specificity is great, buyer and seller will make special efforts to design an exchange relation that has continuity properties' (1981, p. 1546). From the buyer's perspective, this relation should reduce the costs of small numbers exchange and, in fact, Williamson argues that as an asset becomes more specific, it is less costly for the firm to capture the economies of scale itself and bring the asset production under its internal direction. Williamson also argues that internal organization has advantages over market contracting as asset specificity turns the bargaining relationship (at both the contract writing and contract execution stage) into a small-numbers exchange and the hazards of bilateral exchange become pronounced. These advantages are included among those advanced in *Markets and Hierarchies*: (1) it deters pursuit of individual profit streams, (2) it allows

fiat to settle disputes, and (3) it provides more complete access to relevant information to settle disputes by using internal auditors (1981, pp. 1548–1549; 1982, pp. 107–108).

5. Organizational change: Transaction costs, not technology

The basis of Williamson's new economics is his overriding assertion that transaction costs are the determining variables when it comes to the internal organization of the firm (this holds true for all of his writings considered here). In particular, he asserts his independence from traditional industrial organization literature which argues that vertical integration is the result of technological interdependencies in the production process; the standard example is the integration of the iron and steel processes. Williamson denies that this is based on purely technological considerations because the processes could, theoretically, be separated into a sequence of activities which could be completed by a sequence of many firms.

Although Williamson concedes that 'it is sometimes difficult to resist the view that technology really is determinative', he asserts that this is only the case 'if technological nonseparabilities are significant'. This is not true, however, with 'purported thermal economies' such as integrating iron and steel making. Instead, integration of these activities would not be necessary 'if it were possible to write and enforce a complex contingent claims contract between blast-furnace and rolling-mill stages' (1980a, p. 195). It is the basis of Williamson's argument that prohibitive contractual costs are the true reasons that firms choose to shift from the market to internal organization; this is true not only in the steel industry, but for all firms and all industries. Technology may influence the size of the firm, but 'decisions to make or buy, which determine the distribution of economic activity as between firms and markets, and the internal organization (including both the shape and the aggregate size) of the firm are not explained, except perhaps in trivial ways' by technology (1981, p. 1537).

Williamson discusses two types of technological indivisibilities: (1) scale economies whereby larger physical facilities permit decreased average unit production costs and (2) information economies where acquiring information requires an initial set-up cost. In neither of these instances, however, is there a technological need for integration. Instead, a single person (or firm) could own the facilities or the information, respectively, and contract to either supply the services of the asset (produced at reduced costs) or disseminate the information. Thus, Williamson concludes, if it were not for transactional difficulties this type of specialization would occur (1975, p. 42).

There are a few instances where Williamson admits that technology has played a larger role than his dismissals indicate. This was particularly the case with the evolving energy technologies which, as business historian Alfred

Chandler (1977) described in such detail, greatly influenced or accommodated the shift to hierarchy. Here Williamson acknowledges that these technologies of coal and oil created production indivisibilities in metal-making, metalworking, refining, and distilling which made integration highly efficient. Similarly, electric motors turned mass production industries into processes almost as continuous as the heat-using industries (1980a, pp. 187, 189).

Yet, in spite of the admitted consequences of these technologies, he rejects their importance in favor of transaction cost considerations. He argues that the technologies did not dictate particular organizational changes, but rather created situations which would dictate extremely costly contracting. It was these costs, not the technologies, which dictated the organizational changes: 'Flow processes – whether natural (liquids, gases, grains) or devised (assembly lines) – appear simply to dictate organizational outcomes. I submit, however, that tight linkages among processes are technologically determined only if technological nonseparabilities are significant' (1980a, p. 195).

Williamson admits that technology can significantly affect internal organization and even gives an example of a technological change which rendered an organizing mode 'no longer viable' (1980a, p. 188, n. 20), yet he refuses to retreat from his theory of underlying transaction cost economizing: 'I do not...mean to imply that choices of technology and internal organization are independent. To the contrary, technological changes may render some organizing modes inoperable. But as between *feasible* organizing modes (of which there are normally several), differential performance is to be understood as a transaction costs issue. Basically, the question of efficient versus inefficient modes of internal organization comes down to an examination of their properties in bounded rationality and opportunism respects. Organizing modes that economize on scarce information processing and decision-making capability have superior properties in transaction-cost terms, *ceteris paribus*. Similarly, modes that serve to attenuate subgoal pursuit and discourage information hoarding and distortion are favored, *ceteris paribus*' (1980b, pp. 11–12).

Chandler, whose *The Visible Hand* serves as a historical base for Williamson's arguments [Williamson (1984, chap. 5)], has criticized Williamson for giving technology much less credit than it deserves in explaining the internal organization of the firm. Chandler argues that technology both created the national markets which, in turn, created the need for new governance structures and introduced the mass production possibilities which encouraged other new governance structures [Chandler (1982, p. 128)].

Williamson concedes that factors other than transaction costs economizing help explain the creation of the modern firm. But he dismisses technology as being a factor which was only important in determining the physical size of a

firm or a production facility (1981, p. 1537). He goes so far as to admit that his economics may overstate the case, yet he concludes that although 'certain objective features of the technology are important and need to be taken into account...maintaining a transaction-cost economizing focus is warranted' (1982a, p. 111).

In contrast to Williamson's reluctant acceptance of even a limited role for technology, Douglass North has a more broadly-based understanding of the changing business firm in U.S. history which recognizes the interrelationship between technology and transaction costs. North asserts that the new technologies of the 'second industrial revolution' were characterized in the form of large fixed-capital investments and that Chandler's 'managerial revolution' was the effort to realize the productive potential of the new technology. North, however, also criticizes Chandler for missing the other half of the story which was the managerial attempt to reduce the transaction costs attendant on the new technology. These costs were brought about by the significant increase in specialization, division of labor and the number of exchanges which this new technology brought about (North, pp. 175-176). In turn, managers created other technologies in order to reduce these increasing transaction costs (p. 177).

6. Transaction costs as technology

Williamson stridently dismisses the importance of technology in explaining internal organization and the rise of the firm. Yet, in fact, his model relies heavily on technology to both explain its assumptions and to demonstrate the means by which internal organization (hierarchy) overcomes the problems of transaction costs (as North historically explains). This is not simply a matter of semantics, but rather becomes evident by examining Williamson's own vocabulary and comparing it to the current literature on technology (much of it from economists). Although he rejects technology, Williamson has spent little effort explaining what it is he is rejecting (which is much like his decade-long approach to defining transaction costs). Most importantly, at no time does Williamson clearly define technology. Following, and, perhaps, because of this, he does not explicitly recognize that there are forms of technology which are significantly different from the highly physical, production hardware he refers to when he dismisses technology (Dugger, p. 108).

Ironically, however, the body of his writings reveals a more sophisticated, yet not explicit, understanding of other forms of technology. So inexplicit that he ignores his own words. By carefully reading Williamson's argument, it becomes evident that technology plays an important role in both the description and prescriptions of his model.

The three key elements of Williamson's transaction-cost economics are

bounded rationality, opportunism, and asset specificity. In spite of his explicit rejection of technological considerations, Williamson's description of these elements and his prescription of internal organizational solutions, in fact, significantly rely on technological considerations.

6.1. Bounded rationality

Williamson identifies two limits on rationality: neurophysiological and language. Neurophysiological limits are the physical limits which restrict the volume of information the human brain can receive and manipulate. In addressing this transactional weakness Williamson prescribes an explicitly technological solution to mitigate these limits: 'Changes in information processing technology may occur which alter the degree to which bounded rationality limits apply' (1975, p. 10).

Language limits, on the other hand, are those which individuals face when they are unable to articulate their knowledge or feelings (using words, numbers, or graphics) to make others understand them. When this occurs, they must attempt other means of communication. Williamson suggests that one method that gets around this limit is the apprenticeship system which involves learning- and teaching-by-doing and which is 'often the most efficient means of communication for this reason' (1975, p. 255).

By recommending that 'learning-by-doing' be used to alleviate bounded rationality, Williamson invokes a distinctly technological solution. 'Learning-by-doing' is commonly conceived as production experience which either reduces the cost of production or increases the pace of production [Rosenberg (1982, pp. 109–111)]. Williamson asserts that internal organization, rather than the market, improves communication and reduces bounded rationality. It does so by providing a better environment for efficient communication codes to evolve and for parties to use them with more confidence. These codes use an 'idiosyncratic language' to summarize complex events and, thus, economize on bounded rationality: 'Communication systems become effective when they employ languages which carry large amounts of meaning with relatively fewer symbols. Organizations find such things as blueprints, product number systems, and occupational jargon helpful in increasing the efficiency of their communications' (1975, p. 25).

In other words, the strength of internal organization is that it provides these codes more efficiently. Yet even traditional economics recognizes these codes as a description of a firm's production possibilities sets. These sets or functions define the technical relationship between the firm's inputs and outputs. This notion of technology is identified with a 'book of blueprints' or with knowledge of engineers and scientists. The 'blueprints' metaphor suggests that 'knowledge is unitized, organized in packages labeled "all you need to know about X"' [Nelson and Winter (p. 60)].

Thus, although Williamson argues that transaction costs and not technology explain the changing internal organization of the firm, his solutions to the problems of bounded rationalism are technological ones. However, not only does he fail to acknowledge this, his solutions are inadequate even in economic terms. First, Williamson accepts the traditional economic picture of the firm as a production function. Yet this limited view inadequately explains the creation and evolution of the U.S. business firm because it fails to explain how the existing range of technological alternatives came into existence and what specific forces generated them [Rosenberg (1976, p. 63)].

Second, his specific solutions are similarly inadequate because blueprints do not contain an exhaustive account of production methods. In many instances they are 'quite gross descriptions of what to do, and seldom define a detailed job breakdown, much less provide "how to do it" instructions at the job level'. This should be expected because these descriptions generally presume 'the availability of intelligent interpreters drawing on knowledge not contained in the records themselves' [Nelson and Winter (p. 62)].

Finally, this activity of transferring knowledge and feelings is best conceptualized as a form of 'technology transfer' when we broadly define technology as either 'knowledge about how to do things' [Samuels (p. 872)] or as 'a reproducible and publicly communicable way of doing things' [Brooks (p. 10)].

6.2. Asset specificity and opportunism

Asset specificity is the key attribute in Williamson's transaction cost economics: 'a considerable amount of explanatory power turns on the last'. As noted earlier, it is a redefined version of what he previously called a condition of 'information impactedness'. Impactedness resulted from a combination of opportunism and uncertainty which, in turn, led to bilateral trading conditions at contract renewal time. In his current model, (a) an 'intermediate degree' of uncertainty is assumed, (b) opportunism (i.e., individuals' desires to exploit knowledge gained from winning initial bidding contests) remains, and (c) the small-numbers (bilateral) exchange relation is included as a key characteristic of asset specificity. 'Once the investment has been made, buyer and seller are effectively operating in a bilateral (or at least quasi-bilateral) exchange relation for a considerable period thereafter. Inasmuch as the value of highly specific capital in other uses is, by definition, much smaller than the specialized use for which it has been intended, the supplier is locked into' the transaction to a significant degree. This is symmetrical, moreover, in that the buyer cannot turn to alternative sources of supply and obtain the item on favorable terms, since the cost of supply from unspecialized capital is presumably great. The buyer is thus committed to the transaction as well (1981, p. 1546).

Asset specificity can arise in three different ways: site specificity, physical asset specificity, or human asset specificity. Yet, although couched in transaction cost vocabulary, all three are, in fact, technological factors. Site specificity, which results from economizing on inventory or transportation expenses, and physical asset specificity are by all definitions technological in nature. As discussed earlier, for example, even Williamson admitted that changes in energy technology significantly affected the siting and organizing of production facilities. As for physical asset specificity, Williamson specifically defines it in technological terms 'as where specialized dies are required to produce a component' (1981, p. 1546).

The third type, human asset specificity, holds particular interest for Williamson: 'Additional transaction specific savings can accrue at the interface between supplier and buyers as contracts are successively adapted to unfolding events and as periodic contract-renewal agreements are reached. Familiarity here permits communication economies to be realized: specialized language develops as experience accumulates, and nuances are signaled and received in a sensitive way. Both institutional and personal-trust relations evolve' (1982b, p. 107). This description is rife with technological implications.

It is misleading to exclude the communication of knowledge from any definition of technology. Such activities as management science, operations research and organizational theory constitute the technological 'software' of society [Brooks (p. 10)]. Williamson includes 'learning-by-doing', which he also identified as a way to overcome language limits, as another facet of human asset specificity: 'Ordinarily... there is more to idiosyncratic exchange [highly specific transactions] than specialized physical capital. Human-capital investments that are transaction-specific commonly occur as well. *Specialized training and learning-by-doing* economies in production are illustrations' (1979, p. 240; emphasis added). As described earlier, 'learning-by-doing' is commonly conceived in economics as production experience which either reduces the cost of production or increases the pace of production.

Finally, Williamson cites another author to explicitly define human asset specificity as technology: 'Idiosyncratic investments in human capital are in many ways more interesting and less obvious than are those in physical capital. [Michael] Polanyi's discussion of "personal knowledge" is illuminating: "The attempt to analyze scientifically the established industrial arts has everywhere led to similar results. Indeed even in the modern industries the *indefinable knowledge is still an essential part of technology...*"' (1979, pp. 242-243; emphasis added).

This definition of human asset specificity is clearly captured in Nathan Rosenberg's definition of technology as 'itself a body of knowledge about certain classes of events and activities. It is not merely the application of knowledge brought from another sphere. It is a knowledge of techniques,

methods, and designs that work, and that work in certain ways and with certain consequences, even when one cannot explain why' [Rosenberg (1982, p. 143)].

7. Conclusion

In conclusion, Williamson's work is enlightening because it compensates for crucial omissions in traditional economics. Yet, he substitutes the weaknesses of technological determinism – firms are managerial hierarchies because technological efficiency demands it – for the weaknesses of transaction cost determinism – firms are managerial hierarchies because organizational efficiency demands it. Missing in both explanations is a thorough, historical understanding of the interrelationship between technology, transaction costs and institutional arrangements.

Technological knowledge is acquired and diffused within changing institutional settings while, at the same time, technological change creates the opportunity and the necessity to change institutions.³ A key necessity is the need to reduce transaction costs. As North writes: 'Transaction costs and technology are of course inextricably intertwined. It was increased specialization which induced organizational innovations, which induced the technical change, which in turn required further organizational innovation to realize the potential of the new technology' (p. 169). Recent historical work has shown this interdependence as technology and technological change have become better understood. Rather than focussing on individual technologies it has become more helpful to think of technological systems or clusters. These groupings are created as new technologies and institutional arrangements are induced by the presence of complementary innovations and institutional bottlenecks which prevent innovations from being more fully exploited. [Rosenberg (1982, p. 59–61; 1976, p. 113)] Williamson's work would be strengthened by explicitly recognizing the important role which technology plays in his work and the interdependence of transaction costs and technology.

³For example, a recent study by Sanjaya Lall (1979) attempted to determine the propensity of U.S. multinationals to undertake foreign research and development activities. Lall found that the technological nature of the industry strongly influenced this decision. In engineering industries it was 'much more difficult to separate any part of major R&D activity from the main market and the centres of decision-making.... In these industries (as compared to process industries), greater technological intensity seems to create a greater centralization of research activity' (p. 329).

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