Diffusion, uncertainty and firm size

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Studies of the role of small vs. large firms in innovation go back to Schumpeter. In studies of product innovation, recent literature points to a 'dynamic **complementarity**' between small and large firms. In studies of the adoption of (process) innovations (diffusion), the effect of firm size has been studied much less. David (1975) and Davies (1979) proposed models which hinge on some 'critical firm size' beyond which adoption takes place. In these models, risk is not treated explicitly. In the theory of capital investment decisions, adoption is generally treated as a determinate decision based on a trade-off between expected returns and risk.

The present paper presents an alternative model, inspired by the 'behavioral theory' school of economic theory. The decision to adopt is treated as a gamble with odds in favour depending on expected returns and odds against depending on risk. Under reasonable side-assumptions, expected returns are proportional to size and risk is independent of size. This yields a probability of adoption which depends on firm size without any 'critical firm size'. The model is tested and estimated on data concerning the diffusion of general purpose computers in the Netherlands.

The paper closes with a discussion of further research and implications for industrial marketing and for technology policy.

1. Introduction

According to Rosenberg (1982, p. 106) the study of technological innovation consists of a series of footnotes to Schumpeter.' But concerning the role of small firms in comparison with large firms, Schumpeter's work, when considered as a whole, is ambivalent. In his earlier work ("Theory of economic development and business cycles"), Schumpeter proposed the view that innovations are generated by new, small firms. Later (in Schumpeter's "Capitalism, socialism and democracy") this was replaced by the view that innovations are generated more by established, large firms with monopoly power, since only they can command the resources for research and development. Surveys of later work, presented by Scherer (1980), Kamien and Schwarz (1982) and Stoneman (1983), indicate that Rosenberg's general characterization is largely correct, in the sense that the opposition between the 'small firm' and 'large firm' theses is still unresolved.[2] The issue is too complex to allow for a single sweeping statement concerning the relation between innovation and firm size, regardless of types and conditions of innovation. It is plausible and there are empirical indications (see, e.g., Rothwell and Zegveld, 1982; Nooteboom, 1984), that the generation of fundamentally new 'high technologies' (cf. Rosegger, 1980), shifting 'state-of-the-art' boundaries, prior to applications, and complex large scale applications are the province of large firms (or joint ventures or large firms), while applications in novel product/market combinations, product adaptation and product/service combinations are the province of smaller firms. The reasons for this are straightforward: The first class of innovations requires large teams of highly specialized labour and large capital outlays and carries great risks, which only large firms or joint ventures between them can sustain. The second class of innovations requires close interaction with customers and a type of reckless unorthodoxy and flexibility that provides scope for small entrepreneurs.

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[1] Brouwer (1986, p. 749).

[2] It would not be very useful, and would consume too much space to repeat the surveys in the present paper.

As formulated by Rothwell (1985, p. 9): the advantages of large firms are material and those of small firms behavioral. From this, the notion emerges of a certain 'dynamic complementarity' between small and large firms, where small and medium sized enterprises 'play different roles at different periods of time in different industries'.[3] According to the complementarity hypothesis, the different roles of small and large business [4] in the course of the life cycle of a product (or product class) are as follows: generation of new basic technology: large firms (and universities); daring implementation in new product/market combinations: small and medium sized firms; large scale, efficient production and distribution: large firms (often after take-overs of succesful small innovator firms); adaptations for specialized or residual market niches in the maturity phase of the product: small firms (often in the form of product/service combinations).[5]

This complementarity view of small and large business is gaining acceptance as the basis for technology policy, aimed at removing obstacles in the access of small and medium sized firms to information/knowledge and finance, to let them play their role.[6] Implicitly or explicitly, most innovation stud-

ies concentrate on the development and introduction to the market of new products. Some of these products are means of production (materials, processes, methods and tools). An important issue is the adoption (diffusion) of these process innovations, and differences in this area between small and large firms. That is the subject of the present paper. Empirical evidence indicates that small firms are systematically lagging behind in the adoption of process innovations developed by other firms, and the question to be considered here is how this is to be explained.[7]

2. Diffusion and firm size in the literature

In the economics literature, Stoneman (1983) classifies studies of diffusion into three types: intrafirm, intra-sectoral and economy wide. Reviewing the state of the art in intrasectoral studies of diffusion, he discusses the psychological approach, the probit approach and the game theoretic approach. He further identifies four questions for studies of diffusion:

(1) what determines the post-diffusion (saturation) level of use or ownership?

(2) why are some users early and others late?

(3) what time path will use follow and why?

(4) what characteristics of (potential) users are the key factors in influencing that time path?

We add two further questions:

(5) how does use depend on firm size (in the case of process innovations), and why?

(6) how is the decision to adopt taken in view of uncertainty?

See Rothwell and Zegveld (1982, p. 245).

the statistical demarcation of small and medium sized business varies (between different countries and different agencies/institutions within countries) from less than 100 people engaged, to less than 500 or even (many) more people engaged. In manufacturing 100 people is perhaps too low but a boundary much higher than 500 people is not very useful. The notion of complementarity should not be carried so far as to suggest that there is no competition or conflict between large and small business. Complementarity arises mainly on the macro level of the generation and diffusion of innovations. It may also arise on the micro level, in the form of relations of comakership or joint R&D, but it may also go together with fierce competition on the micro level, with small firms challenging large firms in the early phase, small firms being pushed out of the market or being taken over by large firms in the phase of growth, and small firms being kept out of the market in the consolidation phase.

Cf. Rothwell and Dodgson (1987), Dekker Committee (1987), and WRR (1987).

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[7] Empirical evidence on the lag of small firms in the introduction of automation (both general purpose computers and process automation), for example, is given in official statistics and surveys by commercial market research firms (in the Netherlands: the Central Bureau of Statistics and NIPO).

According to the 'psychological approach' (a term attributed to David, 1969), "diffusion takes time because actors respond to stimuli only with a lag, and these lags differ across the population".[8] Much work in this area has been conducted by Mansfield (1968), on the basis of the epidemic or contagion model, yielding a logistic diffusion curve, with profitability and size of the investment as determinants of the speed of diffusion. In his study of the diffusion of computers, Chow (1967) also used the contagion model, but found the Compertz specification to be preferable to the logistic, and included an effect of the price decline of computers on the saturation level of demand. Similar extensions/modifications with respect to the logistic curve have also been studied.' Firm size and decision-making under uncertainty (questions (5) and (6)) are not modelled explicitly. In the game-theoretic approach (Reinganum, 1981) information is assumed to be perfect, firms are assumed to be identical and different adoption dates are derived from a Nash equilibrium in an oligopoly game. Here also, firm size and uncertainty are not included in the analysis.

The probit approach focuses on the characteristics of individuals in the sector and yields results as to which firms are early adopters and which late, and yields results on the effect of firm size. In particular, David (1969, 1975) and Davies (1979) developed models of the 'critical level' type: when some stimulus variate takes on a value exceeding a critical level, the subject of stimulation responds by instantly determining to adopt the innovation in question." Different subjects adopt at different times because either the stimulus variate or the critical level is subject to a distribution of values, rather than a unique value for all subjects. If S is the stimulus variate, with relative density func-

tion f(S), and S*(t) is the critical value at time t, then the proportion of adopters at time t is given as

$$\int_{S*}^{\infty} f(S)\, \mathrm{d}S. \qquad (1)$$

David and Davies both take firm size as the central variable (S), and consider how firm size is distributed within the sector and how the critical or threshold value of firm size is determined. David's (1975) hypothesis is that critical size $S*(t)$ is defined by the point where labour savings due to adoption (assumed to be proportional to size) equal the cost of installing the innovation (assumed to be independent of size). Assuming exponential growth of the wage rate relative to the cost of the innovation, yielding an exponential decline of critical size, and assuming a constant lognormal distribution of firm size, David arrives at a time path of diffusion in the form of a cumulative normal distribution."

As noted by Davies (1979), a limitation of David's model is that it hinges on the 'lumpiness' of the investment: if both costs and benefits are strictly porportional to firm size, the effect of firm size disappears.[12] The hypothesis developed by Davies (1979) is that a firm will use a new technology if the expected pay-off period is less than some critical period, while both the expected and critical pay-off periods are functions of firm size and other firm characteristics. This yields the following ownership condition: adoption by firm i of size $S(it)$ occurs if it exceeds some critical size S * *(it),* where this critical size is proportional to the product of a large number of firm characteristics. Assuming independence of these characteristics an appeal to the central limit theorem yields a lognormal distribution of critical size. This yields a functional relationship between firm size and the probability

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[8] Stoneman (1983, p. 93).
[9] See, for example, Wahlbin (1982).
[10] Stoneman (1983, p. 109).

[11] David (1969).
[12] Davies (1979, p. 31).

of adoption according to a cumulative lognormal curve. The procedure for arriving at this curve is adopted from earlier studies of the diffusion of consumer durables, yielding a cumulative lognormal 'Quasi Engel curve'. The aggregate diffusion curve is now found by aggregating the curve over the size distribution of firms. Using two alternative specifications of the dependency of critical size upon time, for two different classes of innovation, and assuming a lognormal size distribution, Davies arrives at a time path of diffusion according to a cumulative normal or a cumulative lognormal distribution.

The structure of Davies' model is in fact very similar to that of David's model: both models employ critical size, beyond which adoption is certain, and there is no consideration of uncertainty, risk or lack of information in the adoption decision. The main difference (apart from the considerations yielding a critical size) is that Davies attaches a lognormal variate to critical size, on the assumption that the factors determining critical size, in terms of firm characteristics, are many and independent. Those factors are said to include " technical attributes [. . ,] such as the nature of its (the firm's) products, existing processes and inputs [. . .] and [,.,] other attributes such as educational attainment of managers and research intensity [. . .] age of management, degree of internal financing, profit trends, growth performance and other variables influencing attitudes to risk".[13] In fact, studies of small business and their markets indicate that the independence of these attributes from each other and from firm size is questionable, to say the least, and thereby the assumption of a lognormal variate is subject to criticism.

Summing up, different studies of diffusion address parts of the issue which all seem relevant: psychological lags in response, prof-

itability, size and lumpiness of investment, preemptive or retaliatory actions of competitors, time required to recover costs of investment, firm characteristics, relative price of the investment. The effect of firm size hinges on the notion of critical size. Risk is mentioned as a factor in the decision to adopt, but is not treated explicitly in a trade-off with expected profitability. There appear to be no studies which take all relevant factors into account simultaneously, presumably because that would no longer yield a model which is analytically elegant and tractable. Perhaps requisite complexity should be preferred, at the cost of surrendering analytical tractability, which would lead research further along the path of simulation as pioneered, in this area, by Ijiri and Simon (1977) and Nelson and Winter (1974, 1982). Nevertheless, the present paper makes another attempt at an analytical model, with the following focus: adequate treatment of uncertainty in the decision to adopt and of the effect of firm size.

In the marketing literature, a survey of diffusion research has been edited by Mahajan and Wind (1986). The basis is formed by the work of Fourt and Woodlock (1960), Bass (1969), and the work by Mansfield mentioned before. The Bass model is an additive combination of the Logistic model, where the increase of adopters depends on the interaction of potential and actual adopters (imitation effect), and the Fourt-Woodlock model, where the increase depends only on the number of potential adopters (innovator effect). Part of later research was aimed at more general and more flexible diffusion functions. An important line of research for marketing has been the incorporation in the model of marketing mix variables such as price and promotion (for a review, see Kalish and Sen, 1986), and competition against existing and potential firms.

Dolan, Jeuland and Muller (1986) and Eliashberg and Chatterjee (1986) indicated in their review that stochastic considerations, to

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[13] Davies (1979, pp. 68-70).

deal with uncertainty, are not well developed. They report Markov-chain models of transition probabilities between stages in the buying process, which incorporate bayesian learning (derived from the economics literature) and Von Neumann-Morgenstern utility. Chatterjee and Eliashberg themselves are working on a model of the adoption process on the basis of a random walk over pieces of information. Apart from this latter work, models of the decision process which take into account uncertainty appear to be scarce. What work there is, appears to concentrate on adoption decisions by consumers. Work on decisions to adopt process innovations which adequately deals with uncertainty and takes into account the effect of the firm size of adopters does not appear to be available.

3. Decisions under uncertainty

Clearly, the adoption of an innovation entails uncertainty: are expectations (promises from suppliers) concerning cost saving or quality improvement realistic; what unforeseen hitches will arise in adaptations of the innovation to the operating conditions of the firm, or vice versa, adjustments of the firm to the innovation (complementary investments, training, organisation, acceptance, procedures)? The crucial question seems to be: how much spending may be required, and for how long, to bring performance up to standards/ expectations. And the bottom line: what chance is there that in the end the balance of costs and benefits is negative, in which case adoption should not take place? As the innovation matures, risk in terms of the gap between what is expected and what might happen is reduced. Next to improvements in cost/benefit properties, as the innovation matures, this may be the main determinant of diffusion. Clearly, the relevant category is perceived risk, which may decline because more information is available or because in-

formation is diffused more widely and/or is perceived to be more reliable (more colleagues with hands-on experience). This links up with contagion models but with the precise interpretation of reducing risk. Thus the decision to adopt is a two sided issue: expected net present value (NPV) of savings or enhanced revenues on one side, and (perceived) probability of negative net present value (risk) on the other side. NPV and its perceived variance will in general depend on firm characteristics such as: firm size (economies of scale, spread and thereby mutual compensation of risks), expected pre-emptive or retaliatory activities of competitors (with possible asymmetries with respect to firm size), age and educational level of entrepeneurs or staff (correlated with type of product and firm size), degree of risk aversion, time preference of returns as expressed in a discount rate.

Summing up: particularly in the area of innovation it would be descriptively false, normatively wrong and scientifically unfruitful to disregard risk in adoption decisions.[14]

To proceed, the central question now is how the trade-off between expected returns and risk of failure is to be represented. It would be wrong to incorporate risk by adding a risk premium to the discount rate for NPV calculations. The fault in this is that time preference and risk preference are conflated, with the result that risk introduces a systematic bias in favour of short term returns.

Under the assumption of rational and perfect financial markets, in the sense that the shareholder's interest prevails and full information on expected returns and risks of all investment opportunities is available, the decision rule is as follows: invest in an internal

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14 Descriptively false: in fact, entrepreneurs are sensitive to risk, next to expected or possible rewards; normatively wrong: it would not be in the interest of the firm to recommend decisions on the basis of expected returns only; scientifically unfruitful: reduction of risk in time is likely to be a major determinant of diffusion.

project if its NPV is higher than that of a package of traded securities with the same level of risk. There are two problems in this approach. The first problem is that it may be rational even from the shareholders point of view to prefer internal investment opportunities to external investment in traded securities, even if its NPV is lower, for strategic reasons: to establish a basis for future profits, or to provide for a spreading of risks or for flexibility. These aspects are labelled 'options' by Myers (1987, p. 12), who indicates that methods are being developed to incorporate the value of such options in calculations of evaluation that will be solved. The second problem is more fundamental: shareholders' interest may not prevail, and internal investment opportunities are preferred to pay-out of dividends or external investments in securities in order to achieve economically unorthodox objectives of management (growth, market share, number of staff, personal power).[15] The power of management to do so is plausible in view of the first problem: knowing that for strategic reasons internal projects with relatively low NPV may be warranted, it is difficult for shareholders to distinguish legitimate cases from managerial objectives dressed up as strategic options. In fact, management itself may not be able to make the distinction, since strategic evaluations will inevitably be coloured by subjective evaluations and personal views and ambitions. However the normative side of this issue may turn out, descriptively it seems realistic to concentrate on the process of managerial choice from a set of internal investment opportunities. Since different internal alternatives seldom have the same level of risk, the problem now is how expected returns and risk are traded off in the selection of investment projects.
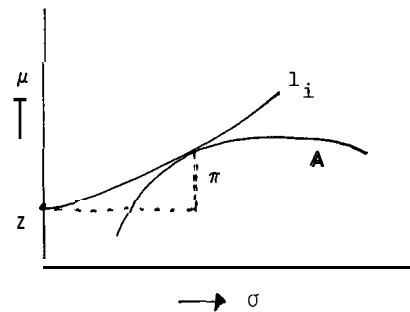

Fig. 1.

There is a considerable body of literature on decisionmaking under uncertainty.[16] A prominent line in this is the approach attributed to Markowitz (1970) on the basis of indifference curves in an expected value (μ) standard deviation (a) plane."

The basic principle is illustrated in Fig. 1. The optimal investment opportunity lies where an indifference curve I(i) is tangent to the set of investment opportunities A. Z is the corresponding 'certainty equivalent': The certain ($\sigma = 0$) revenue an entrepeneur would trade for the investment opportunities with higher expected returns (μ) and higher risks (σ) along the indifference curve. The difference in expected return between an investment opportunity and the corresponding certainty equivalent (π) is the 'subjective price of risk' at that level of risk (a).

Investment occurs if there is at least one opportunity on an indifference curve with a certainty equivalent exceeding the return on a risk free asset (such as a government bond). Investment behavior varies primarily due to differences in the subjective pricing of risk.

A minor point of critisism is that it is not the standard deviation (a) that counts, but the probability that net present value falls below some minimum acceptable level (typically zero, but possibly some other level, below which the firm would go bankrupt). The

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[15] Cf. Marris and Wood (1971).

[16] See, for example, Sinn (1983).
[17] See Markowitz (1970).

difference matters in the case of a skew distribution of returns.

A more fundamental point is whether it is warranted to assume a trade off between expected returns and risk in terms of a 'subjective price of risk', yielding a deterministic choice. What is the nature of this price? Generally, in mainstream economic theory, price is the outcome of supply and demand, and thereby functions as an objective signalling device to producers and consumers, without any need for subjective assessments of value. In the present context of risk evaluation, is there some kind of internal, intrasubjective market determining the price of uncertainty? There may well be a process of deliberation or bargaining, within the organisation, with different attitudes to risk acceptance among different stakeholders, but it is doubtful that this can be represented as an efficient market which yields a stable price of risk which is independent from the investment opportunities considered. A similar objection applies to the use of Von Neumann-Morgenstern utility, whereby it is not expected net present value that is maximized, but expected utility, where the probabilities of outcomes are weighted with utilities attached to them, and then aggregated. Is it reasonable, i.e., behaviorally plausible or realistic, to assume such utility weights as available prior to the decision? Even if experiments show that decision makers, when pressed in an artificial decision environment to choose among options of varying risk, 'reveal' utility weights or indifference curves, this does not demonstrate that they implicitly use such constructs in real decision making. A utility function which is zero for all outcomes below a survival value and unity above that, would yield maximization of the probability of survival, where expected returns are ignored. The point we are trying to make is that decision makers look at both expected returns and risk of failure, without knowing how to merge them into a single measure of merit. Perhaps the two dimensions of the decision cannot be merged so easily. Perhaps they are incommensurable, with the result that the decision-maker vacillates between them, whereby the decision itself becomes probabilistic, with the balance tipped perhaps, by Keynesian 'animal spirits', internal bargaining or accidental circumstance. This would certainly make the obvious effects of 'animal spirits', advertising, personal relations, power structures, confidence, service, image, etc. easier to understand.

In the established framework of deterministic trade-offs between expected returns and risk, these effects remain a mystery, or are ascribed to 'irrationalities' with which economic science has no business." More in the vein of the 'behavioral theory' programme [19] in economics, as explored by Simon (1957), Cyert and March (1963), Leibenstein (1976), Nelson and Winter (1974, 1982) and others, we propose a probabilistic decision situation, in terms of a gambling model of the adoption of innovations. The term 'gambling model' is not intended to suggest that entrepreneurs undertake risky investments purely for the joy of gambling (though that may be part of it), but to indicate that they consider the decision a gamble, lack a clearly defined price of risk, vacillate between expected returns and risk, and arrive at a decision by internal deliberation and bargaining to such an extent, that the decision comes to resemble the rolling of dice loaded by expected return and risk.

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[18] As argued by Weintraub (1985a, b) the standard approach in economics, labelled the 'neo-Walrasian' programme by Weintraub, can be seen as a 'research programme' in the sense of Lakatos (1970, 1978). As such it has a 'core' (rules for constructing theories, which are shielded off from refutation) which contains the assumption that economic agents optimize some objective function subject to constraints, a 'positive heuristic' with the injunction to construct theories in which agents optimize, and a 'negative heuristic' with the extradition of 'irrational behavior' and the injunction 'to keep sociology at bay'.

[19] It has not been and perhaps cannot be established, that it can be considered a research programme in the Lakatosian sense.

In the internal process of deliberation or bargaining, production managers and perhaps also marketing managers may focus on the expected rewards of installing a process innovation (lower costs, higher quality), while financial managers may focus on financial risks and workers may focus on the risks of changing operating conditions. The present approach is consonant with learning theory as applied to decision making.[20] According to this perspective decisions more generally are probabilistic as a result of perceived risk. As experience or knowledge accrues, perceived risk is reduced and the decision becomes more deterministic.

4. A gambling model

The basic hypothesis which is maintained (not directly subjected to falsification) is as follows:

-- The decision to adopt the innovation at time t or to maintain it, if it was already adopted in the past, is proportional to expected net benefits in the future.

- The decision not to adopt at time t or to disadopt (scrap), in case of adoption in the past, is proportional to the probability of failure, defined as the probability that net benefits are negative.

Of course, for a given firm the two probabilities should sum to unity.

This yields

$$p = \frac{E}{E + \rho \cdot \mathrm{pf}}, \qquad (2)$$

where

p = probability of ownership,

E = expected net present value of returns (NPV),

pf = probability of failure, i.e., of negative NPV,

[20] Cf. Wiswede (1985).

ρ = a parameter expressing the weight attached to risk pf relative to expected returns E. ρ also includes a scaling coefficient depending on the unit of measurement of E ($\$$, guilders, 1000 guilders, . . .).

This basic model may be the start of an on-going research effort to develop models of increasing sophistication. There are many ways of specifying the stream of costs and benefits over time, with associated probability density functions, and with possible differences between firms who have already adopted and those who have not.

In particular, the following questions arise:

- What, if any, is the 'vintage effect': if adoption takes place at time t, what are the *real* effects on the costs/benefits of that vintage of the innovation, from technological progress and accumulated learning after t?

- What determines the *perceptions* of decision makers (or influencers in the decision process) : present technology and present potential of the firm (extrapolation of current conditions); all the available, limited knowledge concerning future conditions (rational expectations); full knowledge of future conditions as they will actually be (clairvoyance)?

Only in the case of clairvoyance would there be no need for probability density functions (no risk), and would the decision be based on a balance of certain costs and benefits (in present value terms). The most realistic assumption would probably be that perceptions of future costs and benefits are based on: characteristics of decision maker(s), own experience in case of adoption in the past, and partial incorporation of external knowledge and experience (also depending on characteristics of decision maker(s)). Assumptions have to be made as intermediate hypotheses, in order to arrive at the end result of a model of ownership as a function of firm

size. One can now choose from the following approaches:

Direct testing. Form alternative intermediate hypotheses; test them directly on relevant data; pick the hypothesis that yields the best empirical performance; use this to develop the model of ownership (which can then in turn be tested empirically).

Indirect testing. Conduct a mathematical study of the implications of different intermediate hypotheses for the specification of (alternative) models of ownership, and test the latter on relevant data. In this way the intermediate hypotheses are tested only indirectly. Different intermediate hypotheses may yield the same model of ownership, with different interpretations of the parameters.

Pragmatic approach. Go directly to the specification of the simplest possible model of ownership that still has sufficient plausibility on the level of intermediate assumptions, and test this against an alternative that is somewhat less restrictive on the level of intermediate assumptions. Depending on the results and on the interest in refinements of the model, consider more sophisticated assumptions on the intermediate level.

The present article reports the results of the third ('pragmatic') approach. The main reason for taking this approach was that it is the shortest one, and insights were required at short notice for the purpose of policy formation. More sophisticated models are currently under consideration.

To arrive at the simplest possible model, the present assumptions are as follows:

(1) Each firm faces a probability distribution (density function) of future net returns, in present value terms, per unit of firm size S (S is measured in number of people involved or volume of output).

(2) This distribution of returns per unit of firm size does not depend on firm size. This implies: no economies or diseconomies of scale; no dependence on firm size of perceptions of costs and benefits; no dependence on

firm size of the discount rate used for present value calculations.

(3) The distribution does not depend on whether or not the firm adopted the innovation in the past. This implies that there is no learning or other benefit from past adoption other than that incorporated in expectations shared by all possible users (in the sample of firms studied): previous adopters have no advantage. It also implies that current technology can be fully incorporated in previous vintages of the innovation: previous adopters have no disadvantage.

(4) The weight attached to risk of failure relative to expected returns (parameter ρ in (2)) does not depend on firm size.

Clearly, these assumptions are very restrictive, and call for discussion.

Assumption (1). This assumption by itself does not seem problematic.

Assumption (2). Smaller firms are expected to be less knowledgeable about opportunities and risks than larger firms. As a result they may be more pessimistic or on the contrary more optimistic, so that a priori the impact on adoption decisions is not clear. Economies or diseconomies of scale may occur, but again it is a priori not clear which is the case.

In the case of (general purpose) computers, for example, implementation may be relatively more costly in larger organisations due to the larger number of people or hierarchical levels of organisation involved, yielding more complex and lengthy communications, deliberation and procedures. On the other hand, it may be cheaper and faster due to a higher level of education/training and the availability of more specialized expertise. Smaller firms are expected to be less oriented towards the longer term, and thus to employ (implicitly or consciously) a higher discount rate.

Assumption (3). Past adopters may face other future streams of costs and benefits than non-adopters, and this may depend on how long ago adoption took place. A priori, it is hard to say what the balance of ad-

vantages/disadvantages or earlier adopters is. For example, consider the case of (general purpose) computers. On the one hand, past experience will yield improved prospects for future returns: people are trained and have experience; computer programmes have been debugged; new applications may have been developed in house; new and better outside software may be implementable. On the other hand, new applications may not be implementable, due to incompatability with older systems, or may involve a change of knowledge/experience which is more costly than starting from scratch.

Assumption (4). Smaller firms may be systematically less risk averse than larger firms, but the reverse may also be true. Small business is often divided into two groups: technology driven, risk seeking firms and more conservative, passive followers. The first type is expected to be less risk averse than large business, and the second type is expected to be more risk averse than large business. On this score, there are also correlations with the age of the entrepreneur, his educational level and age of the firm. Therefore, the influence of firm size will depend on the composition of the sample studied. The attitude towards the risk of employing the innovation will also depend on the penalty attached to its failure relative to the total size of the firm's operations, and the correlation of that risk with the risks involved in other activities of the firm. In this respect, one would in general expect larger firms to be less risk-averse, due to a larger size of operations combined with a greater spread (less correlation) of risks. However, in the case of general purpose computers, it seems reasonable to assume that adoption pervades all activities of the firm. That is also why we assume costs and benefits to be proportional to firm size.

These issues should ideally be subjected, one by one, to empirical research. Since a priori it is not clear in which directions factors will operate, and in what way, we start

with the hypothesis that they do not occur or cancel out, in order to arrive at the simplest possible model that may apply. This model will be tested empirically against a more general model that allows for a more complex effect of firm size (since that is the effect we are most eager to study). In the present study, only a very limited attempt will be made to model the change of parameters in time, and no attempt is made to model differences between new and past adopters.

Under the specified assumptions, expected net returns are as follows:

$$E(S, t) = \varepsilon(t)S \qquad (3)$$

where

E(S, t) = expected net returns, in present value, of a firm with size S, at time ι,

$\varepsilon(t)$ = expected net return per unit of firm size, resulting from ownership at time t.

The probability of failure was defined as the probability that returns will be negative, which equals the probability that expected net return per unit of size is negative. Since by assumption the corresponding probability density function is independent of size, we have

$$\mathrm{pf}(S, t) = \varphi(t) \qquad (4)$$

where

pf(S, t) = probability of failure, for a firm with size S, at time t,

$\varphi(t)$ = probability of negative net returns per unit of firm size.

Substitution of (3) and (4) in (2) yields

$$p(S, t) = \frac{\varepsilon(t) \cdot S}{\varepsilon(t) \cdot S + \rho \cdot \varphi(t)} = \frac{S}{S + \alpha(t)},$$

$$\alpha(t) = \frac{\rho \cdot \varphi(t)}{\varepsilon(t)}, \qquad (5)$$

where

$p(S, t)$ = probability of ownership of a firm with size S at time t.

Summing up, the model hinges on two sets of assumptions:

– probability of ownership is proportional to expected net returns and probability of non-ownership is proportional to risk of failure,

– expected returns from ownership are proportional to firm size and probability of failure is independent of size.

This model will be tested against a more general specification:

$$P(S, t) = \frac{S^\beta}{S^\beta + \alpha^*(t)}, \quad \beta \neq 1. \tag{6}$$

This specification allows for dependence on firm size of: expected net return per unit of firm size (economy or diseconomy of scale), risk aversion and risk of failure.

5. Properties of the model

Model (5) implies that smaller firms are slower to adopt than large firms. It further implies

$$\lim_{S \to 0} p(S, t) = 0, \qquad \lim_{S \to \infty} p(S, t) = 1. \tag{7}$$

In other words: firms of zero size never adopt, and as firm size (and hence available funds) approaches infinity, adoption will be certain. This seems reasonable. The model further implies

$$\frac{\delta p}{\delta S} = \frac{\alpha}{(S + \alpha)^2} = \frac{1}{\alpha}(1 - p)^2, \text{ so that} \tag{8}$$

$$\lim_{S \to 0} \frac{\delta p}{\delta S} = \frac{1}{\alpha}, \qquad \lim_{S \to \infty} \frac{\delta p}{\delta S} = 0. \tag{9}$$

According to (5), α is proportional to risk (probability that net returns per unit of firm size are negative) and inversely proportional to expected net returns per unit of firm size. Given this specification (based on earlier simplifying assumptions) it is reasonable to make

the further assumption that α will consistently decline in time, and will ultimately reduce to zero, because technological progress will increase expected returns, and the dispersion of the probability density of returns will reduce, thus reducing risk, as the innovation matures and its potential becomes settled, well known and standard. What this says, of course, is that the innovation becomes less and less innovative. It is also reasonable to assume that the decline of α will level off, due to decreasing returns of technological improvement and learning by doing. Thus, we assume

$$\frac{d\alpha(t)}{dt} < 0, \quad \frac{d^2\alpha(t)}{dt^2} > 0, \quad \lim_{t \to \infty} a(t) = 0. \tag{10}$$

This does not preclude that α reaches zero at some finite point in time rather than in infinity. It follows from (9) that as α declines in time, the curve of p in relation to S rises ever more sharply from $S = 0$. The above properties are illustrated in Fig. 2, where the curve of p in relation to S is plotted for different values of α, which results from the later empirical study of the diffusion of computers in Dutch retailing. Model (5) also implies

$$\frac{\delta p}{\delta t} = \frac{-S}{(S + \alpha)^2}\frac{d\alpha}{dt} = -p(1 - p)\frac{d \log \alpha}{dt}. \tag{11}$$

If α has a fixed percentage decline rate, (11) shows that the increase of ownership percentage, for a given firm size, is largest when ownership is 50%. With a fixed decline rate, (11) reduces to the differential equation of the logistic equation (for each level of firm size), [21] which has a point of inflection at 50% diffusion.

[21] The assumption of a fixed percentage decline of α (exponential decline) would imply $\lim_{t \to -\infty} a_t = \infty$, and hence $\lim_{\to -\infty}(S, t) = 0$. This would imply that there is always a nonzero probability of adoption, no matter how far we go back in time. But something that has always been available can hardly be called an innovation.
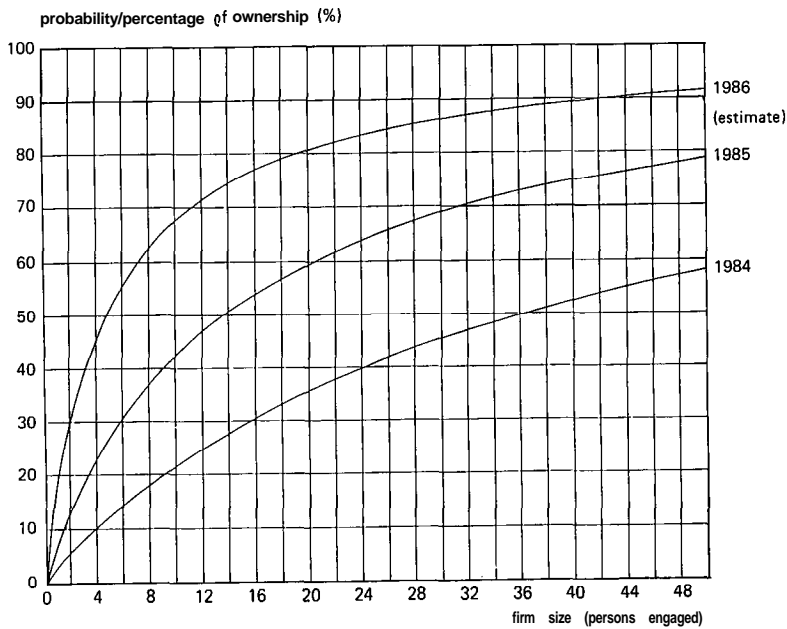
probability/percentage of ownership (%)

Fig. 2. Size-dependent ownership for independent Dutch retailers.

For the totality of all firm sizes, the expected percentage of ownership is

$$\bar{p}(t) = \int_0^\infty p(S, t) f(S)\, dS$$

$$= \int_0^\infty \frac{S}{S + \alpha(t)} f(S)\, dS, \qquad (12)$$

where $\bar{p}(t)$ is the expected percentage of owners at time t, in a given sector (all firm sizes), and f(S) is the density function of the size distribution of firms. This diffusion curve satisfies the following boundary condition:

$$\lim_{t \to \infty} \bar{p}_t = 1 \quad \text{(following from (7)).} \qquad (13)$$

In other words, ultimately all firms will employ the innovation. The exact shape of the diffusion curve depends on the shape of the size distribution. So far, it has been implicitly assumed that the size distribution does not change in time. This assumption can be abandoned. The model offers a framework for studying the effects of increase of scale, concentration or deconcentration on the diffusion of technology. There may be several causes of changes in size distribution, includ-

ing the size-dependent diffusion of technology itself. The earlier introduction of technology by larger firms may favour their competitive position or profitability relative to smaller firms. But such a study of size distribution and its interaction with technology is beyond the scope of the present paper.

6. The data

The empirical part of the present study involves:
- a formal test of the relationship between ownership and firm size p(S),
- a more informal test of assumptions concerning the time path of $\alpha(t)$.

The data were obtained from a telephonic inquiry among 1000 independent retailers in different types of trade in the Netherlands, conducted in September 1984. The shopkeepers were asked whether they operated a (general purpose) computer, when it was installed, or whether they had an any plans for installing a computer before end 1985, if they

did not already have a computer. The addresses for the inquiry were sampled from a panel of 6000 independent retailers operated by the Research Institute for Small and Medium Sized Business in the Netherlands (EIM). The sample was distributed and weighted across different types of trade to be representative of independent retailing in the Netherlands.

The data on computer ownership were grouped in cells according to size of staff (number of people engaged, including the shopkeeper and his family; in full-time equivalents).

As already indicated, there were data for different points in time: plans for purchase before end 1985, ownership in September 1984, and information whether, in case of ownership, a computer was already owned in 1983, 1982 or 1979. There is a possibility to segment the data for total retailing into classes of different types of trade. Finer segmentation of course yields fewer observations per class. For the purpose of testing and estimating our model, we chose to segment the total sample into two subclasses: [22]

(a) the top seven types of trade in terms of computer ownership, with a total of 271 firms observed. These types of trade were, in the order of average ownership: electrical goods, clothing, books, shoes, sportswear, furnishing and do-it-yourself goods.[23]

(b) the remainder of the total sample (705 firms observed).

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[22] This choice was based on a rather intricate argument, The cells of observation were re-arranged so as to equalize, as much as possible, the variance of computer owners per cell. The total sample was segmented in two classes in such a manner, that they would yield equal numbers of cells, for 1984 and 1985, with equal variance in all cells.

[23] the reader may be surprised not to find the general food trade in this class. The reason is, that this type of trade has its needs covered to a large extent, not by the general purpose computer considered in this study, but by dedicated systems in the form of scanning, cashing on the basis of Price Look-up systems, automated scales and portable devices for taking stock and registering orders.

Table 1 yields all the relevant data for these two classes and the total sample.

7. Tests and estimates of the effect of firm size

The empirical tests and estimates ae based on the fact that the model (5) is a transformation of the standard logistic model:

$$p = \frac{1}{1 + \exp(\beta_0 + \beta_1 x)}. \qquad (14)$$

If we substitute x = log S, β_0 = log α, and β_1 = -1, this transforms into our model (5). With $\beta_1 = -\beta$, it transforms into the more general specification (6). Tests and estimates were made by means of a maximum likelihood procedure for logit models developed at the "Stichting voor Economisch Onderzoek" (Foundation for Economic Research) at the University of Amsterdam, which yields standard errors and allows for restrictions on the coefficients. For further details on underlying theory and technique, see Cramer (1986). The procedure' was as follows:

- substitution of log S as the explanatory variable;
- unrestricted estimates of β_0 (as an estimate of log α, which is then transformed into an estimate of α ($\hat{\alpha}$) and β_1 (as an estimate of β). This corresponds to the more general version of our model (6);
  estimate of β_0 under the restriction β_1 = − 1. This corresponds to the simple model (5) which we wish to test against the alternative (6). This yields an estimate of the parameter α in the simple model ($\hat{\alpha}$).

The procedure is applied for different years to the two sets of data discussed in the previous section (top seven trades and remaining trades). The results are given in Table 2. In all cases the estimates of the parameter α according to the restricted logit model (corresponding with out hypothesis (5)) are strongly significant, have the correct sign and decline consistently in consecutive years, as expected.

Table 1

The basic data, for the finest available grid of cells, where n = number of firms, k = number of firms with computer (end of year. except 1984), $\bar{S}$ = average firm size in the cell (number of persons engaged)

(a) Total sample

Year		Size class (number of persons engated)								
		0.1-0.9	1-1.9	2-2.9	3-3.9	4-4.9	5-6.9	1-9.9	10-19.9	> 20	Total
	$\bar{S}$:	0.20	1.31	2.21	3.25	4.19	5.68	1.99	13.08	36.44	4.71
	n:	0	152	229	166	123	124	93	72	17	976
1985 [a]	k		8	27	38	29	31	27	36	11	206
1984 [b]	k		3	12	13	7	14	9	19	11	89
1983	k		2	8	6	4	6	4	15	8	51
1982	k		2	4	2	3	5	1	8	6	31
1979	k	−	2	1	2	3	2	−	2	3	14
1977	k					2	2			1	5

(b) The top *seven* types of trade (electrical goods, clothing, books, shoes, sportsgoods, furnishing, do it yourself)

Year		Size class								
		0.1-0.9	1-1.9	2-2.9	3-3.9	4-4.9	5-6.9	7-9.9	10-19.9	> 20	Total
	$\bar{S}$:	−	1.32	2.24	3.23	4.26	5.47	8.33	12.73	23.71	
	n:		30	57	47	38	33	31	25	10	271
1985 [a]	k		3	8	17	16	13	13	13	8	91
1984 [b]	k		1	4	6	6	4	4	7	8	40
1983	k			1	2	3	2	2	7	6	24
1982	k			1	1	3	2	−	4	5	14
1979	k			1		3	−	−	1	1	7
1977	k			−		2				1	3

(c) Remaining types of trade

Year		Size class								
		0.1-0.9	1-1.9	2-2.9	3-3.9	4-4.9	5-6.9	7-9.9	10-19.9	> 20	Total
	$\bar{S}$:	0.20	1.31	2.20	3.26	4.16	5.76	1.95	13.27	47.19	4.55
	n:	1	122	172	119	85	91	61	47	8	706
1985 [a]	k		6	20	20	12	19	14	23	4	117
1984 [b]	k		3	8	6	1	10	5	12	4	48
1983	k		2	7	4	1	4	2	8	2	29
1982	k		2	3	2	−	3	1	4	2	16
1979	k		2	−	2	−	2	−	1	2	8
1977	k						2	−	−		2

[a] 1985 based on plans registered in September 1984.

[b] 1984 observed in September.

The test of the simple model (5) against the more general model (6) is a test of the hypothesis $\beta_1 = -1$.

A t-test on the estimates of β_1, in the unrestricted logit model, indicates that the hypothesis is to be rejected only in one out of the ten cases (at the 95% confidence level). A comparison between the loglikelihoods (log L) of the unrestricted and restricted logit models shows that the likelihood declines only

little in going from the unrestricted to the restricted model. The significance of this decline is tested with a likelihood ratio test, as follows:

$$LR = 2(\log L_1 - \log L_2),$$

where log L, refers to the unrestricted model and log L_2 to the restricted' model. LR is chi-square distributed with one degree of freedom. LR is significantly different from zero

(95% confidence level) in only one of the ten cases (the same case as indicated by the t-test).

LR can be summed across the ten cases, yielding a value of 10.24 with ten degrees of freedom, which is far from significant. The estimates for the restricted model were also made for all types of trade taken together, to test whether the results were significantly less likely than those for the two groups (top seven and remaining trades) taken apart. The conclusion was that the separation into the two groups did indeed yield more likely results.

8. The time path of a

In Fig. 3, the estimates of α (see Table 2) are plotted against time, [24] to see whether they conform to the expectations and hypotheses discussed in Section 5 (formula (10)). The results appear to confirm the hypothesis that α yields a monotone decline. The results appear to contradict the hypothesis that the second derivative of α is everywhere positive: in relevant ranges the slope of the decline appears to be fairly fixed. In other words the decline is often more linear than curvilinear. The hypothesis that the decline of α would consistently level off was based on the assumption of diminishing returns of technological progress and learning by doing.

The results indicate that a zero value of α is reached very closely, not in the very long but in the fairly short term. In the case of the top seven trades that point appears to be reached in 1987 at the latest, and in the case of the remaining trades a year or so later. Within the framework of the model the results indicate that either for the increase of expected returns or for the decline of uncertainty, or both, there are no diminishing re-
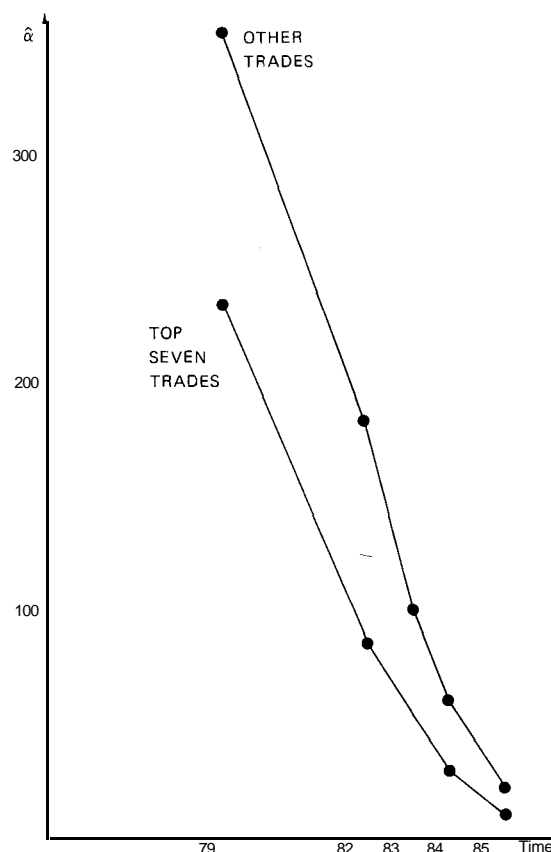

Fig. 3. Decline of $\hat{\alpha}$.

turns of technology and learning until α has become quite small.

Table 3 shows that the percentage decline of the estimates of α increases in time. The explanation of this faster than exponential decline of α is a matter for further research.

9. Further research

Further research is planned to test and estimate the model on a much wider sample of data across all sectors of the Dutch economy. The formal results are not available yet, but an impression is given in Figs. 4 and 5. The figures give the degree of automation (percentage of firms with a computer) in relation to firm size for the main sectors of the

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[24] In contrast with the other years, the data point in 1984 is located at 0.75 of the year, since it applies to an observation in September.

Table 2
Estimates of the logit model with and without restriction."

	Without restrictions			Restriction $\beta_1 = -1$		
	$\hat{\alpha}$	$\hat{\beta}_1$	$\log L_1$	$\hat{\alpha}$	$\log L_2$	**LR**
Top seven trades:						
1979	139.60	-0.72	27.908	236.33	-28.046	0.276
	(146.13)	(0.54)		(98.37)		
1982	285.37	-1.61	-50.427	82.99	-51.809	2.764
	(246.76)	(0.38)		(21.81)		
1983	266.19	1.79[b]	-62.100	55.13	-65.022	5.844[b]
	(206.65)	(0.35)		(12.34)		
1984	38.57	-1.17	-101.141	28.31	-101.388	0.494
	(18.70)	(0.25)		(5.04)		
1985	8.71	-1.00	-158.297	8.69	-158.297	-
	(2.88)	(0.20)		(1.18)		
Other trades:						
1979	332.19	-0.96	-45.261	355.29	-45.265	0.008
	(252.74)	(0.37)		(120.14)		
1982	158.74	-0.92	-75.348	183.38	-75.389	0.082
	(88.42)	(0.28)		(45.64)		
1983	76.36	-0.84	-117.488	99.90	-117.732	0.488
	(32.15)	(0.22)		(19.03)		
1984	67.13	-1.07	-162.629	59.54	-162.696	0.134
	(24.42)	(0.19)		(9.06)		
1985	18.39	-0.95	-294.921	19.99	-294.994	0.146
	(4.43)	(0.14)		(2.11)		

[a] Standard errors between parentheses; **LR** is chi-square distributed with one d.f.
[b] Significant deviation from the hypotheses $\beta_1 = -1$

Dutch economy in 1983 and 1985, on the basis of data from the Dutch Central Bureau of Statistics. For an estimate of the model, attempts are under way to obtain the data for a more detailed break down into more homogeneous sectors (subsectors of manufacturing; separation of retailing, hotels/restaurants/cafe's and repairs; subsectors of business services). At this stage, Figs. 4 and 5 are presented to show that the relation between degree of automation and firm size appears to be very much like the pattern predicted by our present model (see Fig. 2). After further tests of the model of the relation between degree of automation and firm size, the parameter α will be estimated per sector, for different years, and further research will concentrate on explanations of the development in time of α, and of its difference between different sectors.

A complementary line of research would be to investigate alternative specifications of the model on the basis of a reevaluation of the simplifying assumptions discussed in Section 4 of the present article. This would probably lead to more complex models, allowing for more complex effects of firm size and additional explanatory variables and parameters

Table 3
Average percentage decline of α (%).

	1979–1982	1982–1983	1983–1984	1984-1985
Top seven trades	30	34	59	61
Remaining trades	20	46	50	59

[a] Account has been taken of the fact that the observation in 1984 took place in September, while the other observations were made at the end of the year.
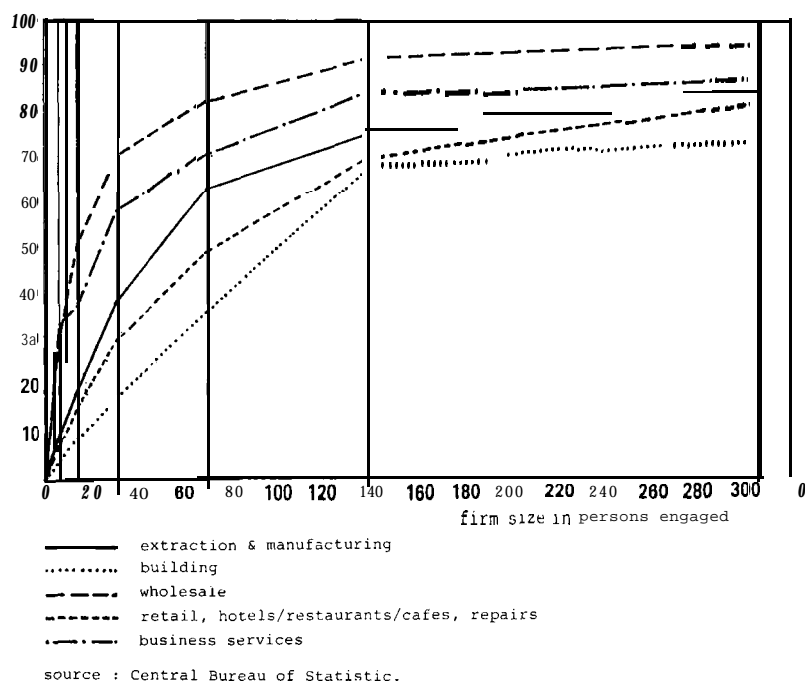
extraction & manufacturing
building
wholesale
retail, hotels/restaurants/cafes, repairs
business services

source : Central Bureau of Statistic.

Fig. 4. Degree of automation (% of firms with a computer), 1983.

extraction & manufacturing
building
wholesale
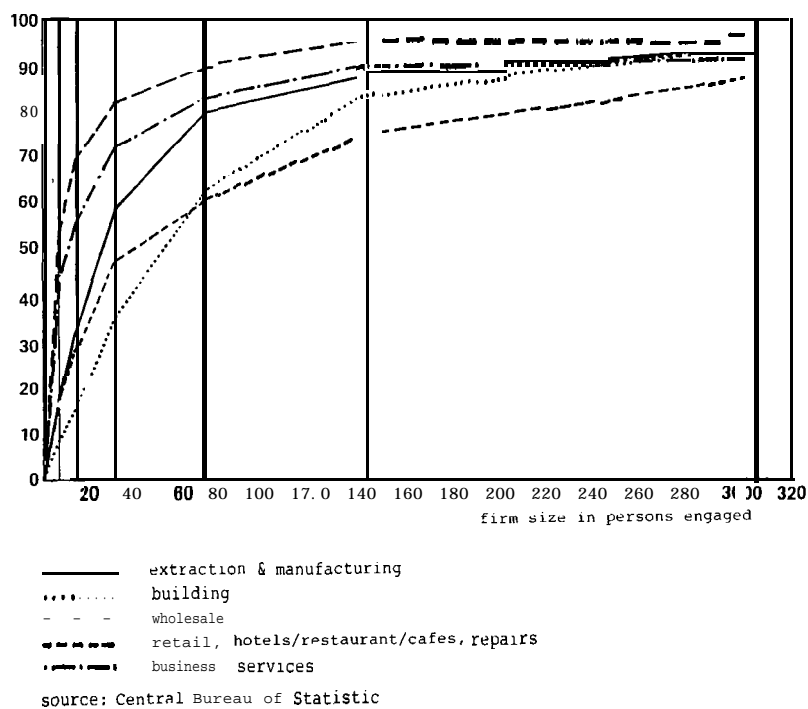retail, hotels/restaurant/cafes, repairs
business services

source: Central Bureau of Statistic

Fig. 5. Degree of automation (% of firms with a computer), 1985.

(characteristics of potential adopters, market structure, marketing mix variables of suppliers, etc.). It would probably also lead to different decision models for new and old adopters. A simple assumption concerning old adopters would be that there is no way back: once an innovation is adopted, it is maintained. A more sophisticated approach would be to take into account the scrap value and productivity of older vintages of the innovation compared to current costs and state of the art. In this way the model would expand into a model of both new purchases and replacement purchases.

This might well be of interest to suppliers of computers or software. Another line of research would be to apply the ideas and methodology for the development of diffusion models for other innovations where the effect of firm size is considered to be important.

10. Practical implications

In contrast with David's model, discussed in Section 2, the present model does not hinge on the 'Lumpiness' of the investment. This is an advantage. In the case of (general-purpose) computers, for example, computing facilities can now be purchased at very low size and cost (microcomputers). In contrast with Davies' model, the model does not hinge on the independence of many firm characteristics related to pay-back period. In contrast with both David's and Davies' models, the model does not look only at expected costs and benefits, but also at uncertainty.

There are practical implications on two levels: technology policy and industrial marketing. Relevant decision makers in technology policy are government agencies, advisory bodies, associations of entrepreneurs, trade organizations, etc. In industrial marketing one might think of producers and distributors of innovations for business (e.g., com-

puters), and associated business services (in the case of computers: software houses, automation consultants).

In the area of technology policy, the model was used to answer two questions that were urgent at the time (1985):
- To what extent is the lag of small business in the adoption of computers an indication of weak management that requires action on the part of policy makers and advisory bodies?
- What are the implications of the widening lag in adoption between small and large business, that was observed in 1984, and what pattern of diffusion can be expected for the future?

On the basis of the present study, the answers were as follows:
- It is rational for entrepreneurs to make a trade-off between expected returns and risk. On the (reasonable) assumption that expected returns are proportional to size and risk is independent of size, it is only to be expected that small firms will lag behind (i.e., this has a rational basis).
- Due to the S-curve properties of the diffusion curve, it is to be expected that the gap between large and small businesses widens at first. Later (our prediction, in the case of retailing, was around 1986), the gap would start to close very fast.
- If government or associated institutions for advice and counselling to small business were to make policy and undertake action, it should be directed not at pressing entrepreneurs to install computers, but at reducing perceived risk by means of realistic and accessible information on costs and benefits, and on improving expected benefits by stimulating applications (systems and software) relevant for small firms.

For industrial marketers, the practical implications are as follows:
- The model may be used 'as an aid for planning by predicting market demand, and for segmentation by indicating in what seg-

ments of firm size growth is to be expected in the near and in the further future.

The model demonstrates that in determining the allocation of funds for improved market position, a trade-off should be made between improving performance (shifting the probability density of costs and benefits to higher levels of net returns) and reducing perceived risk (narrowing the dispersion of the probability density at a given level of performance). The latter may be sought in improved reliability (as opposed to level) of performance, more reliable and accessible communication of possible applications and associated costs and benefits, and more implementation support, training of users, demonstrations, manuals, guarantees of performance or buy-back guarantees in case of failing applications. It is not only improved performance but also reduced risk that can offer competitive advantage.

The model might also be used to differentiate prospective sales in different segments between competing suppliers, and may be extended to include marketing mix variables. This could yield a more systematic trade-off between quality, price, distribution, service and communication, as a refinement of the trade-off between costs/benefits and risk reduction.

References

Bass, F.M.. 1969. A new product growth model for consumer durables. Management Science 15, 215-227.

Brouwer, M., 1986. Developments in the theory of industrial organisation (2) (in Dutch). Economisch Statistische Berichten, 30 July.

Chow, G.C., 1967. Technological change and the demand for computers. American Economic Review 57, 1117-130.

Cramer, J.S., 1986. Econometric applications of maximum likelihood methods. Cambridge: University Press.

Cyert, R.M. and J.G. March, 1963. A behavioral theory of the firm. Englewood Cliffs, NJ: Prentice-Hall.

David, P.A., 1969. A contribution to the theory of diffusion. Stanford Centre of Economic Research in Economic Growth, Memorandum no. 71.

David, P.A., 1975. Technical choice, innovation and economic growth. Cambridge: University Press.

Davies, S., 1979. The diffusion of process innovations, Cambridge: University Press.

Dekker Committee, 1987. Switching point between knowledge and market (in Dutch). The Hague, April.

Dolan, R.J., A.P. Jeuland and E. Muller. 1986. Models of new product diffusion: Extension to competition against existing and potential firms over time. In: V. Mahajan and Y. Wind (1986). 117-149.

Eliashberg, J.R. and R. Chatterjee, 1986. Stochastic issues in innovation diffusion models. In: V. Mahajan and Y. Wind (1986), 151-199.

Fourt, L.A. and J.W. Woodlock, 1960. Early prediction of market success for grocery products. Journal of Marketing 25, 31-38.

Ijiri, Y. and H.A. Simon. 1977. Skew distributions and the sizes of business firms. Amsterdam: North-Holland.

Kalish. S. and SK. Sen. 1986. Diffusion models and the marketing mix for single products. In: V. Mahajan and Y. Wind (1986), 87-116.

Kamien, M.I. and N.L. Schwartz, 1982. Market structure and innovation. Cambridge: University Press.

Lakatos. I., 1970. Falsification and the methodology of scientific research programmes. In: I. Lakatos and A. Musgrave (eds.). Criticism and the growth of knowledge. Cambridge: University Press.

Lakatos, I., 1987. The methodology of scientific research programmes: Philosophical papers, vol. 1. Y. Worrall and G. Currie (eds.), Cambridge: University Press.

Leibenstein, H., 1976. Beyond economic man. Cambridge. MA: Harvard University Press.

Mahajan, V. and Y. Wind (eds.), 1986. Innovation diffusion models of new product acceptance. Cambridge, MA: Ballinger.

Mansfield, E.. 1986. Industrial research and technological innovation. New York: Norton.

Markowitz, H., 1970. Portfolio selection: Efficient diversification of investments (2nd. ed.). London: New Haven.

Marris, R. and A. Wood (eds.), 1971. The corporate economy. London: Macmillan.

Meyers, S.C., 1987. Theory and practice of capital investment decisions. remarks given at the opening of the Tinbergen Institute, Rotterdam, June 12.

Nelson, R.R. and S. Winter, 1972. An evolutionary theory of economic change. Cambridge, MA: Harvard University Press.

Nelson, R.R. and S. Winter, 1974. Neoclassical vs. evolutionary theories of economic growth. Economic Journal. 886-905.

Nooteboom, B., 1984. Innovation, lifecycle and the share of independents: Cases from retailing. International Small Business Journal 3, no. 1, Autumn. 21-33.

Reinganum. J., 1981. Market structure and the diffusion of new technology. Bell Journal of Economics 12. 618-24.

Rosegger, G., 1980. The economics of production and innovation: An industrial perspective. Oxford: Pergamon.

Rosenberg, N., 1982. Inside the black box: Technology and economics. Cambridge: University Press.

Rothwell. R., 1985. Innovation and the smaller firm. First International Technical Innovation and Entrepreneurship Symposium. Utah Innovation Foundation, Salt Lake City, 11-13 September.

Rothwell, R. and M. Dodgson, 1987. Technology-based small firms in Europe: The IRDAC results and their public policy implications. Second International Technical Innovation and Entrepreneurship Symposium, Birmingham, l-4 September.

Rothwell, R. and W. Zegveld, 1982. Innovation and the small and medium sized firm. London: Francis Pinter.

Scherer, F.M., 1980. Industrial market structure and economic performance (2nd ed.). Chicago: Rand-McNally.

Simon, H.A., 1957. Models of man. New York: Wiley.

Sinn, H.W., 1983. Economic decisions under uncertainty. Amsterdam: North-Holland.

Stoneman, P., 1983. The economic analysis of technological change. Oxford: University Press.

Wahlbin, C., 1982. A new descriptive model of inter-firm diffusion of new techniques. Proceedings of the European Academy of Advanced Research in Marketing, Antwerp, I-2/43-49.

WRR, 1987. To the measure of small and medium sized business, part II: Proposals (in Dutch). A.F.M. Nijsen, B. Nooteboom, C.W. Kroezen, J.J. Godschalk, J. Buursink, WRR report no. 30, Scientific Council for Government Policy, The Hague, The Netherlands.

Weintraub, E.R., 1985a. General equilibrium analysis: Studies in appraisal. Cambridge: University Press.

Weintraub, E.R., 1985b. The missing chapter: Empirical work and its appraisal. Symposium for J.J. Klant, Amsterdam, 18-19 December.

Wiswede, G., 1985. Eine Lerntheorie des Konsumverhaltens. DBW 45, 544-557.