

# **An Adaptation of the Bass New Product Diffusion Model for Multiple Purchases of Capital Items**

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## ***Abstract***

*This paper offers an adaptation of the Bass new product diffusion model to deal with the limitation of the classical model to situations in which each customer only ever purchases a single item. While this assumption is often reasonable in relation to consumer durables, it is rarely warranted for capital items used by businesses. The authors exhibit the case of a start-up technology company; this company has developed a specialized instrument that increases the efficiency of drug evaluations in pharmaceutical laboratories. The paper proposes a technique for incorporating into the Bass model multiple 'follow-on' sales subsequent to satisfactory evaluation of an initial 'trial' purchase. The paper also suggests techniques for estimating and updating the parameters of the model for use in sales forecasting using a proposed research questionnaire.*

## ***Key words***

*New Product Diffusion, Bass model, Sales Forecasting*

## **Introduction**

The process by which new products, once launched, are diffused in the market place is critical to their ultimate success and is of crucial importance in planning their marketing strategy. Although many variants have been explored, models of this process have been primarily designed to explain and predict the process by which households adopt new technologies incorporated in infrequently purchased durable products (Meade and Islam 2006). The key assumption behind these models is that customers (households) will only purchase one or at most a very small number of the item (Mahajan, Muller & Bass, 1990).

In industrial or business-to-business (B2B) markets the single-purchase assumption is often unrealistic. Companies buying new capital equipment may often purchase multiple items to meet their needs. Often, however, they will commence by purchasing a single example item for evaluation purposes and then, if satisfied with its performance, proceed to purchase many further units in order to meet their full requirements.

The sales forecasting model described in this paper is designed to meet the needs of a start-up company which has developed an instrument for use in pharmaceutical laboratories that incorporates a unique, patented technology. The use of this technology enables the laboratories to perform evaluations of potential new drug compounds much more efficiently; once adopted, multiple units are expected to be purchased to meet each laboratories needs. However, being a new technology, customers insist on trialing the instrument before investing substantively in it.

The model developed incorporates the trial-then-repeat purchase process as an adaptation of the well-known Bass new product diffusion model (Bass 1969). Development of this model forms the first step in an ongoing collaboration between the authors and the start-up company. Research methods for collecting data to be used for estimating the parameters of the proposed model are also considered.

## **Literature Review**

Modelling the new product diffusion (NPD) process became established in the marketing literature thanks to the work of Bass (1969), Arndt (1967), Frank, Massey and Morrison (1964), King (1963), Robertson (1967), and Silk (1966). Probably the most influential of the various

approaches has been the Bass model which distinguishes between two distinct processes at work during new product diffusion: innovation and imitation. By estimating only two parameters, a *coefficient of innovation* ( $p$ ) and a *coefficient of imitation* ( $q$ ), the model yields the widely observed 'S-shaped' curve of market penetration that shows a slow initial take up as 'initial adopters' are persuaded to enter the market, succeeded by a rapid growth phase while many imitators decide to follow their lead, and finally a slowing down phase as the market reaches saturation. Different forms of this model have been used to understand and, to varying extents, forecast the innovation process in a wide variety of industrial and consumer settings. Formative developments include Akinola (1986), Dodds (1973), Kalish and Lilien (1986), Lancaster and Wright (1983), Lawton and Lawton (1979), Nevers (1972), and Tigert and Farivar (1981). Many extensions of the original Bass formulation have been developed (e.g., Mahajan 1979; Lilien, Rao & Kalish 1981; Mahajan and Peterson 1985; Mahajan and Wind 1986). These developments have been designed to incorporate: various marketing mix variables such as pricing and promotion, the impact of introductions of successive generations of a new product concept, and replacement purchases of an obsolete or failed item (as distinguished from multiple purchases of an item), among others developments (Meade and Islam 2006).

A number of different approaches have also been taken to the estimation of the two parameters  $p$  and  $q$  in the Bass model. Ordinary Least Squares, Maximum Likelihood, Bayesian and Non-linear Least Squares estimation procedures have all been proposed to determine values for the coefficients endogenously (e.g., Schmittlein and Mahajan 1982; Srinivasan and Mason 1986; Lenk and Rao 1989). Van den Bulte and Lilien (1997) point out some interesting regularities in these estimates as more data becomes available. Use of exogenously determined values has been recommended in situations where little or no data is available. Such an environment is by definition the norm when a truly new product is being marketed for the first time and no suitable parallel marketing situations exist. Sultan, Farley and Lehman (1990) used a meta-analysis based on other published studies to estimate values for  $p$  and  $q$  and found them to be fairly stable with average values of 0.03 and 0.38 respectively. However, a number of scholars recognize the need for more work in this important area. This is particularly important since, as Meade and Islam (2006) point out, most past contributions have emphasized the explanation of past behaviour rather than forecasting future behaviour. Another recent review article (Peres, Muller & Mahajan 2010) focuses on the process of the market penetration of new

products and services that is driven by social influences, which include a variety of interdependencies among consumers. The concentration is therefore NPD within a consumer behaviour rather than a B2B context. In both settings, however, theoretically sound and practically effective models are required. In particular, scholars have called for models that taken into account multiple purchases of the new product by a single purchaser (Mahajan, Muller & Bass, 1990).

One of the first to take up this challenge were Bayus, Hong and Labe (1989), who follow the NPD diffusion paradigm and consider multiple-unit ownership of durable goods. They developed a model of aggregate multiple-unit purchases as a discrete time replacement equation according to the time of the first purchase, i.e., an age-based model. The model was applied to consumer colour television purchases.

Hahn et al. (1994) looked at forecasting the sales of a new entrant into a market for *frequently purchased* pharmaceutical items (e.g., analgesics), in a setting where there is a single established competitor in a mature market. A four stage model is proposed where, in each period, the doctors controlling purchases are split between non-triers, triers, post-trial non-repeaters, and post-trial repeaters. The model combines the Bass innovation/imitation concept with parameters which reflect the propensity of the trialists to repeat their purchases. Like Bayus, Hong and Labe (1989), the model is not based on Bass-type hazard functions, but on a system of discrete time difference equations. The model assumes that each potential customer is a buyer of the product in each period and estimates using aggregate data across a number of different pharmaceutical introductions of the relevant parameters.

Steffens (2003) studied consumer purchases of durable consumer goods in relation to products where a proportion of households might acquire additional units after their initial purchase. An extension of the Bass model was developed, in which a hazard function that determines additional purchase behaviour, since additional purchases are considered 'an innovation from the adopter's perspective' (p.5). A diffusion model between three stages—non-purchasers, purchasers and repeat purchasers—was proposed and its performance estimated in relation to data for historical colour television and automobile data.

Other recent developments in the NPD literature should also be noted. Danaher, Hardie and Putsis (2001) consider the impact of assuming successive generations of products, while Boswijk and Franses (2005) add an additional variable as well as incorporating heteroscedastic errors into

the model. Kim, Shin, Park and Yang (2009) successfully apply the Bass model in a technology diffusion setting (namely, IPTV patents) where, once again, only a single adoption rather than repeat adoptions will take place. Frenzel and Grupp (2009) review various innovation diffusion models and provide a useful categorization of them. They point out the importance of developing realistic hypotheses about the individual case in order for practitioners to choose the appropriate approach. This paper endeavours to follow this advice in relation to a start-up company which the authors have been advising on its sales forecasting techniques.

### **The Company**

The Company with which the authors are collaborating offers an innovative technology to a well-defined international market. Its novel technology, ‘lateral ultrasonic thrust’, using a micro-electro-mechanical systems based transducer, creates bulk acoustic waves which are capable of mixing bio-chemical reagents more rapidly and more homogeneously than existing technologies. Improving the speed and reliability of mixing both increases the likelihood of the positive identification of new drugs, and decreases the likelihood of investing time and effort in unfruitful clinical trials.

Pharmaceutical and biotechnology companies, the target customers, are looking for new ways to identify promising clinical candidates faster in early stage testing and to ensure the accuracy of testing results in later stage testing. Today, these target customers are identifying potential new drugs at the same pace as they were ten years ago. This stagnant rate of discovery comes despite their continued investment in compound screening. High throughput screening labs are spending significant amounts of money on sophisticated equipment and they are utilizing higher density *micro-titer plates* in which they can test more compounds at a time. However, due to the limitations of existing methods to mix and solubilize, the data obtained is not always accurate. Using the Company’s technology, target customers will have the ability to successfully use higher density micro-titer plates without increasing the degradation of the assay signal. Improving the speed and reliability of mixing can significantly decrease the time and cost required to bring new pharmaceuticals to market. Its application can also allow pharmaceutical laboratories to re-examine proposed compounds in their chemical libraries that had previously

been rejected because of their low solubility. Such ‘secondary recovery’<sup>1</sup> potentially offers significantly increased demand for the Company’s instruments. It is evident that the new technology brings a novel market situation for modelling and forecasting purposes.

The Company’s initial target markets are the pharmaceutical and laboratory automation industries. It estimates that these target customers have approximately 5,400 pharmaceutical laboratories worldwide of which, conservatively, half could be potential purchasers of the instrument. In this common B2B marketing situation, the key trial is undertaken after an initial purchase which can be expected to be determined by the familiar innovation/imitation mechanism. If that trial proves satisfactory, then multiple purchases can be expected to follow fairly rapidly (i.e., within a year or two after the initial purchase). Our aim therefore is to model both the initial trial purchase process using the familiar Bass NPD approach but also the process by which these significant extra ‘follow-on’ sales accrue.<sup>2</sup> The Company has considerable interest, for the purposes both of venture capital funding and of expansion plans, in forecasting the total (initial and subsequent) sales of its instrument.

## **The Model**

Our main hypothesis is that the classic new product diffusion process, as described in the Bass model may not be appropriate in situations where multiple further purchases may occur after the initial trial purchase. As a result the ultimate diffusion curve of market penetration may be shaped quite differently as a result. We also hypothesize that a model can be built which makes use of market research information gathered from existing and potential customers during the product launch period to improve the estimates of the model parameters.

To summarize, our aims in building the model are fivefold:

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<sup>1</sup> The term ‘secondary recovery’ is borrowed from the oil industry where it is used to describe the process by which new techniques are used to extract more oil economically from previously abandoned oil fields.

<sup>2</sup> In common with other NPD models, eventual replacement sales are ignored, since, for the items in question, replacement is likely to occur beyond the planning horizon for the Company.

1. To capture the trial and repeat purchase behaviour
2. To be useful for forecasting
3. To be amenable to parameter updates derived from survey data
4. To hold to existing models as appropriate
5. To be as simple as possible

The chosen structure uses a standard Bass model (i.e., hazard function formed using the difference between the current value of a variable and an upper bound, such as market size) for ‘adoption’ of the instrument in an initial trial, and a more simple hazard function model for trial success.

We assume, based on discussions with the Company, that success of a trial is determined endogenously by the purchaser rather than exogenously, even if a certain amount of ‘hand-holding’ by the Company’s technical support team may have some impact on the decision. Thus, unlike Steffens (2003), we do not apply a direct Bass-like innovation/imitation formulation to the repeat purchase situation. Instead, we assume that once success amongst the ‘trialists’ have been established, strong assumptions over the pattern and timing of subsequent purchases can be made. Unlike the model of Hahn et. al. (1994), these follow-on purchases are not part of a continuous re-purchase pattern but are aimed at investment during a short time period in sufficient capital stock of the instruments to meet the buyers’ overall needs.

Granted a two-year purchase horizon for capital equipment investments, we define variables as follows:

Let  $N1(t)$  be the number of trialists at time  $t$ . This is the number of customers that have tried or are trialing the instrument.

Let  $N2(t)$  be the number of satisfied trialists at time  $t$ . This is the number of customers who have completed trialing and were satisfied; they will purchase more items (if they need for more than one instrument in total for their needs).

Let  $N3(t)$  be the number of satisfied trialists at time  $t$  who have purchased more instruments in the first year following trial.

Let  $N4(t)$  be the number of satisfied trialists at time  $t$  who have purchased more instruments in the second year following trial.

Let  $M(t)$  be number of potential trialists at time  $t$  (i.e., the market size defined as the total number of organizations that might buy one or more units). Since we are considering an extended temporal horizon, we in principle allow the market size to vary, by making  $M(t)$  a function of time  $t$ .

The dynamics of the proposed model are captured through a set of hazard function equations:

$$d/dt N1(t) = ( M(t) - N1(t) ) ( p + q N1(t) )$$

This is the classic Bass NPD formula for  $N1$ , i.e., for trial adoption.

$$d/dt N2(t) = ( s N1(t) - N2(t) ) \alpha$$

Satisfied trialists evolve at a constant rate from the number of trialists. We define the constants  $s$  and  $\alpha$  below.

$$d/dt N3(t) = ( (1-s1) N2(t) - N3(t) ) \beta$$

Satisfied trialists who purchase more in their first year after trialing evolve at a constant rate from the number of satisfied trialists who need to purchase more in their first year.

$$d/dt N4(t) = ( (1-s2) N3(t) - N4(t) ) \chi$$

Satisfied trialists who purchase more in their *second* year after trialing evolve at a constant rate from the number of satisfied trialists who purchase more in their first year, and who need to purchase (still) more in their second year.

The constant in the model that need to be estimated are as follows:

$p$  and  $q$  are the familiar coefficients of innovation and imitation used the standard Bass NPD model.

$s$  is defined as the probability that a trialist will be satisfied with the performance of the instrument after making an initial purchase, i.e., the *coefficient of satisfaction*.

$s1$  is defined as the probability that a satisfied trialist does not need to buy any more units since a single instrument is sufficient for all his organization's needs (i.e., total purchase for such customers is one unit).

$s2$  is defined as the probability that a satisfied trialist does not need to buy any more after the year in which the organization purchases the trial instrument (i.e., total purchase is one trial unit together with additional year 1 purchases).

$\alpha$  is defined as an endogenous factor for rate of satisfaction.

$\beta$  is defined as an endogenous factor for rate of purchasing additional instruments in year 1, i.e., the year in which the organization purchases its trial unit.

$\chi$  is defined as internal factor for rate of purchasing additional instruments in year 2, i.e., the year after the year in which the organization purchases its trial unit.

This model formulation makes several major assumptions at the current formative stage in its development. Foremost, we assume that  $F1$  and  $F2$  are the constant number of additional purchases made by satisfied trialists in years 1 and 2 following their trials, respectively. These two constants are therefore mean values over customer organizations in the market.

In the initial phases of the model use, each of these parameters needs to be estimated either with reference to similar model formulations in other contexts or from in-depth discussion with Company personnel familiar with the market, leading to informed estimates. Compared to the

universe of potential customers for, say, an automobile or any other consumer durable, the number of potential users of or customers for the Company's instrument is small. However, all the potential users are labs who are facing a similar research problems, and are thus much more likely to be influenced to use the Company's instrument in response to external influences such as a poster presentation or peer-reviewed article from a top-tier bio-pharmaceutical company (e.g. AstraZeneca, Bristol Myers, Merck, Novartis, or Pfizer) or in response to others in their company who report good success with the instrument. Accordingly, we have set the parameters  $p$  and  $q$  slightly higher than the averages reported by Sultan et al. (1990) in their meta-analysis.

At the same time, the authors intend to launch a significant empirical market research exercise among current and potential future customers to enable refinement of the initial estimates of the other model parameters. Examples of the two forms of the proposed research questionnaires, for current and potential customers respectively, are attached to the paper (Appendix 1 and 2).

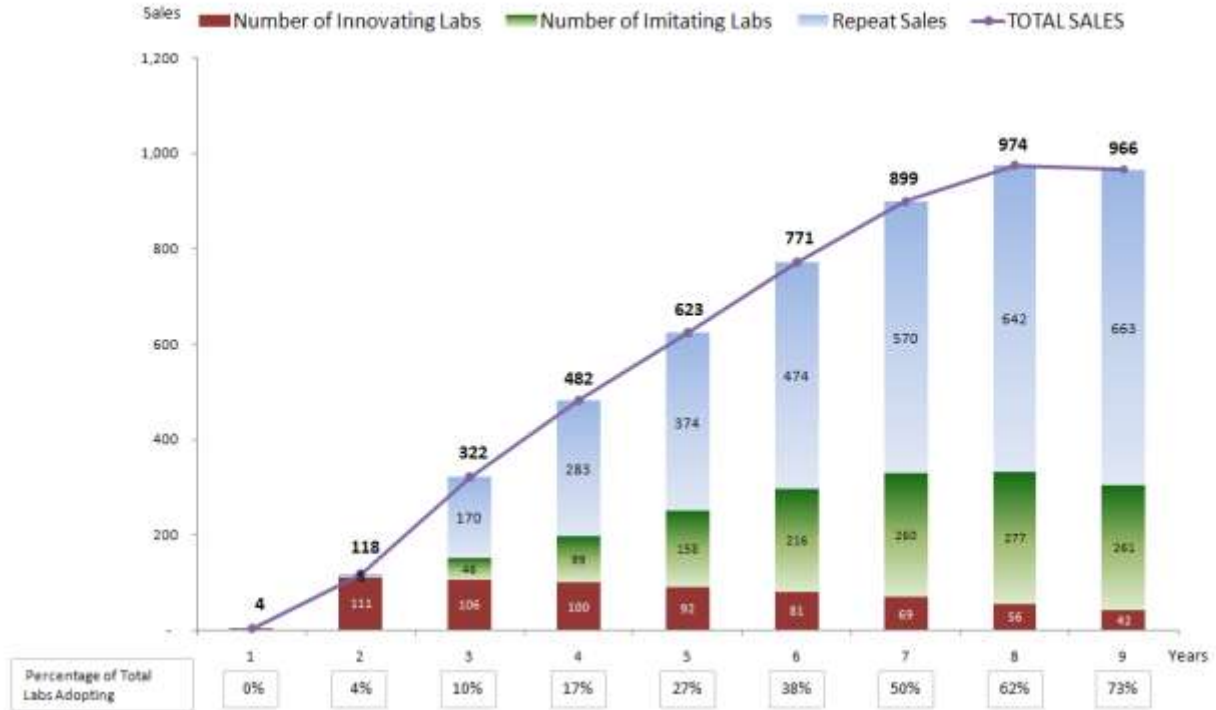
The value of the model to the Company is that it can be used to make a forecast of the total number of units likely to be purchased at a given time  $t$  in the future. This, by definition, will be the sum of the number of units purchased by entities in the trial, year 1, and year 2 classes, i.e.,  $N2(t) + F1 * N3(t) + F2 * N4(t)$ .

A simple illustration of this approach is shown in the table below, based upon recasting the model structure from a continuous to a discrete time period framework. The resulting sales growth curve shows the make-up of forecast sales compared with that obtained using the standard Bass approach. As would be expected the build-up of sales is greater and extends over a longer period in our formulation.

Note that the sales pattern generated is significantly different from a standard Bass model which is represented by the total of sales to new adopters (i.e. the total of innovating and imitating shown in the chart). Repeat sales rapidly increase in importance, even when very conservatively assuming a 50% satisfaction rate ( $s$ ). By year 3 the volume of repeat purchases is greater than the sales to new adopters (i.e., innovators and imitators combined) and by year 9, when over 70% of the potential market has tried the instrument, repeat sales represent nearly 70% of the total.

**Exhibit 1**

**Illustrative application of the model to preparing sales forecasts**



Assumptions used:

$M$ = number of potential buying laboratories	2,700
$p$ = coefficient of innovation	0.041
$q$ = coefficient of imitation	0.410
$s$ = coefficient of satisfaction	0.40
$s1$ = coefficient of satisfaction after trial (probability no further units required)	0.25
$s2$ = coefficient of satisfaction after year 1 (probability no further units required)	0.00
$\alpha, \beta, \chi$ = rate factors	1.00
$F1$ = follow on purchases per satisfied lab one year after initial purchase	3.00
$F2$ = follow on purchases per satisfied lab two years after initial purchase	1.00

## **Conclusions and Directions for Further Research**

This paper illustrates a possible way forward in using NPD models in a B2B market situation which, while arguably common enough for capital equipment, has received limited attention by previous researchers. As such, it represents an update on a work in progress for the product of a technology start-up company whose technology innovation has opened a novel market.

Our aim is to refine the model through incorporating the results of the market research initiative among both current and potential future customers. While the results of these surveys could possibly lead us to decide to alter the model's mathematical structure, they will certainly enable us to develop more reliable values for the model parameters. We anticipate doing this by adopting a Bayesian approach to updating these values (Lilien, Rao & Kalish 1981). This will require the development of a methodology for combining the survey responses with sales data in such a way as to progressively modify the model parameters as new information becomes available. This represents a challenge, but will give us an opportunity to develop some distinctively innovative approaches. Much work therefore still needs to be done both in terms of fieldwork and theoretical thought. At present this represents a limitation of our research as presented here.

Despite the extensive legacy of applying NPD models to single-purchase consumer goods, forecasting multiple purchases of capital items using this approach remains a wide field for research attention. The implications for marketing and management of pursuing this line of enquiry are important not only for start-up companies like the one described in this paper but also for well-established firms. Having better models to forecast the eventual potential size and speed of development of new product markets of this type will enable managers to estimate more accurately the likely investment required and the timing and scale of likely returns. This will enable them not only to decide more effectively which projects to pursue but also to determine the most appropriate marketing strategies to support innovation, imitation and repeat purchase. We therefore believe that continuing this research will yield important benefits at both a theoretical and practical level.

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## Appendix 1

### Proposed Questionnaire for Current Customers

Customer Name .....

Organization .....

Date .....

*In order to help plan our future marketing activities, we would like to ask you some questions concerning your organization's experience with our fluid processing instruments and your future interest in buying instruments from the Company.*

1) *First, we would like to know for which of the following business units you are able to provide us with information. (Please give answers for the largest business unit for which you can confidently speak.);*

a) All your labs worldwide..... How many labs are there? .....

*Or*

b) All the labs in your region..... If so, which region (e.g. Europe, America).....  
How many labs are there? .....

*Or*

c) All the labs in your country..... If so, which country..... How many labs are there? .....

*Or*

d) Just your laboratory.....

2) *In relation to the business unit selected above, please estimate the pattern of influence on the decision to purchase our fluid processing instruments in the past. Please indicate whether or not the following information was available to you and how important it was (or would have been to you) at the time the purchase decision was made:*

a) Comparative data from a third party in a peer-reviewed journal. Available / Not available

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

b) Comparative data from a third party in a presentation poster Available / Not available

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

c) Knowledge that a comparable laboratory was using the instrument Available / Not available

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

d) Comparative data provided by the Company Available / Not available

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

e) Internal evaluation by your organization of the instrument Available / Not available

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

f) Other (Write in)..... Available / Not available

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

g) Other (Write in)..... Available / Not available

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

3) Briefly describe the applications for which the instruments have been used?

.....  
.....

4) Has the instrument(s) performance met your expectations? ..... YES.....NO

5) If NOT why not?

.....  
.....

6) I would now like to ask you some questions concerning your organization's future interest in purchasing more Company instruments for the business unit for which you are able to speak. How many additional instruments do you think this business unit might purchase in the next two years?

For the same application ..... For new applications.....

Describe the proposed new applications  
 .....  
 .....

7) *Please estimate the pattern of influence you expect to affect these future purchase decisions. On the scale shown below, rank the importance of the following sources (assuming they are available).*

a) Comparative data from a third party in a peer-reviewed journal.

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

b) Comparative data from a third party in a presentation poster.

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

c) Knowledge that a comparable laboratory was using the instrument.

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

d) Comparative data provided by our Company.

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

e) Internal evaluation by your organization of the instrument's capability

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

f) Other (Write in).....

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

g) Other (Write in).....

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

8) *In relation to future orders, how long do you expect it to take for your business unit to do the following steps?*

a) From completing of an instrument demonstration by us to recommending purchase?  
 .....months

b) From recommending purchase to issuing purchase order?  
 .....months

## Appendix 2

### Proposed Questionnaire for Prospective Customers

Customer Name .....  
Organization .....  
Date .....

*In order to plan our future marketing activities, we would like to ask you some questions concerning your organization's future interest in purchasing the Company's fluid processing instruments.*

- 1) *We would first like to know for which of the following business units you are able to provide us with information on (Please give answers for the largest business unit for which you can confidently speak.)*

All your labs worldwide..... How many labs are there? .....

*Or*

All the labs in your region..... If so, which region (e.g. Europe, N.America) .....  
How many labs are there? .....

*Or*

All the labs in your country..... If so, which country.....  
How many labs are there? .....

*Or*

Just your laboratory.....

- 2) *In relation to the business unit selected above, please estimate the pattern of influence you expect to affect its decisions concerning the eventual purchase of the Company's fluid processing instruments.*

*On the scale shown below, rank the importance of the following factors in your purchase decision as they become available.*

- a) Comparative data from a third party in a peer-reviewed journal.

Not at all important    0   1   2   3   4   5   6   7   8   9    Extremely important

- b) Comparative data from a third party in a presentation poster

Not at all important    0   1   2   3   4   5   6   7   8   9    Extremely important

c) Knowledge that a comparable laboratory was using the instrument

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

d) Comparative data provided by the Company.

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

e) Internal evaluation by your organization of the instrument's capability

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

f) Other (Write in).....

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

g) Other (Write in).....

Not at all important 0 1 2 3 4 5 6 7 8 9 Extremely important

3) *Again, considering the business unit for which you feel able to speak and assuming that the performance of our instruments meets expectations, how many instruments do you think this business unit might purchase in the next two years?*

.....

4) *Briefly describe the applications for which these instruments might be used*

.....  
.....  
.....

5) *In general, when you do purchase instruments, how long does it take for your business unit to perform the following steps?*

a) From completion of an instrument demonstration by us to recommending purchase?  
.....months

b) From recommending purchase to issuing purchase order? .....months