A cross-national study of lead-lag effect in takeoff of technology life cycle: Two generations of technology in cellular telephone industry

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ABSTRACT

Earlier research has identified market entry timing in the growth phase of a technology/product life cycle as one of the key success factors of market selection and entry decision. However, the cross-national dynamics of the start of the growth phase in the technology life cycle concept remains to be unexplored. Dynamics of this takeoff point is of special practical interest since if companies were able to anticipate takeoff point they would be prepared to plan their operations like product development, manufacturing, distribution etc. to respond to rapidly changing and growing markets.

This article builds the existing knowledge base by explicitly considering the dynamics of the takeoff point from the cross-national point of view. The study reports findings that support existence of an ‘elbow-shaped’ dynamics with clear-cut end of introductory phase in technology life cycle considering two generations of cellular telephone technologies. Further the paper reports supporting evidence that there is a lead-lag effect in a cross-national takeoff timing i.e. leading countries have longer introductory phases in their national technology life cycle.

Keywords: technology life cycle, cross-national, takeoff, lead-lag effect

INTRODUCTION

Companies have been facing ever more consolidating and open global marketplace in recent years. New markets have opened-up (like the countries in former Eastern block countries), national boundaries are falling (like the North American Free Trade Agreement) and free flow of information further facilitates increasing integration of local markets (e.g. Hofstede et al., 1999). Even locally operating companies face foreign competitors that are using global strategies and operations to increase their competitiveness. Multinational and local companies are constantly making decisions in this global marketplace regarding which products to introduce in which markets, when and how the market entry should be made (e.g. Davidson and Harrigan, 1977).

Companies, their customers, governmental agencies, non-governmental agencies (NGOs) etc. are also engaging in interaction with each other in a global scale, across national boundaries, making the picture even more complex. Resulting from the international interaction is cross-national learning (Putsis et al. 1997, Mahajan and Muller, 1994). The cross-national information sharing is especially important in early phases of technology or product life cycle since information needs are high in both supply and demand sides (Howard, 1983, Farrell and Saloner, 1986, Waite et al., 1999). Few studies have explicitly addressed the cross-national dynamics of the early phases of the technology or product life cycle. Takada and Jain (1991) report that when an innovation is introduced first in a lead country and with a time lag in other countries, the diffusion is faster in lagging countries compared to the lead country (positive lead-lag effect). However, their study is limited in geographical scope including only 4 countries in different cultural settings. Also Ganesh and Kumar (1996) and Ganesh, et al. (1997) and Kumar et al. (1998) report similar positive lead-lag effect in a limited country setting. However, Helsen et al. (1993) report negative lead-lag effect and Conde and Ruiz (2001) do not find support for the positive lead-lag effect. Therefore, there exists contradicting evidence of the cross-national lead-lag effect.

Technology and product life cycle in the international setting has been traditionally studied with diffusion models (e.g. Gatignon and Robertson, 1985, Gatignon et al., 1989, Helsen et al., 1993, Putsis et al., 1997, Dekimpe et al., 1998, Talukdar et al., 2002). The earlier research on international technology life cycles has mainly concentrated on comparing diffusion parameter estimates between countries, determination of market saturation point and its timing and growth rate of life cycle. In order to explain differences in diffusion parameters between countries these studies have reported findings that diffusion process is both product and country specific and cross-national influences are having effect on life cycles as well (e.g. Kumar et al., 1998, Takada and Jain, 1991, Tellefsen and Takada, 1999).

Diffusion models have been criticized in applied international setting from a number of points of views. Heeler and Hustad (1980) report difficulties on fitting diffusion models in international setting. Mahajan, Muller and Bass (1990) noted in their diffusion research review that parameter estimation for diffusion models is primarily of historical interest. Reliable estimation also requires that data span across inflection point into the growth phase of technology or product life cycle (Schmittlein and Mahajan, 1982). Further, Dekimpe et al. (1998) show how estimation of diffusion parameters can be risky and misleading in international setting.

According to Rogers (1995) a technology takes off when it passes from the market introduction phase to the growth phase in its life cycle trajectory. The introductory phase is characterized by slow growth rate that is followed by sharp increase in the growth rate resulting in a takeoff point between two phases (e.g. Mahajan, Muller and Bass, 1990, Rogers, 1995, Klepper, 1997). Golder and Tellis (1997) provide empirical research on the takeoff phenomenon reporting an 'elbow-shaped discontinuity' in the life cycle curve in contrast to expected smooth curve. Their study, however, concentrated on the takeoff phenomenon in a national level using the US sales data of 31 product categories. In conclusion they detail that time it takes for a product category sales to reach the takeoff point vary considerably between product categories and pricing has a clear effect on the takeoff timing. Agarwal and Bayus (2000) report results from a study in industry structure and its relation to takeoff. Their findings conclude that the number of firms in the industry increase before the sales takeoff point. Sales takeoff timing has been explained also with the entry strategy of companies. For example, declining price and aggressive penetration strategy with wide distribution have been found to accelerate the takeoff timing of life cycle in many studies (e.g. Horsky, 1990, Chatterjee and Eliashberg, 1990, Golder and Tellis, 1997). Further, Montaguti et al. (2002) present a conceptual framework for companies to use in accelerating takeoff timing in a marketplace but they do not consider explicitly dynamics of takeoff timing or its measurement in their study.

In making market entry decisions the entry timing is critical to the success of entry (e.g. Golder and Tellis, 1993, Shankar et al., 1999, Di Benedetto, 1999, Lambert and Slater, 1999, Mahajan and Muller, 1998). Market entry at the growth stage of the life cycle has been found to be beneficial in contrast to pioneering advantages (Shankar, et al., 1999). Missing the start of the growth phase also easily leads to operational problems like missed delivery dates and quantities, no matter whether this occurs to pioneer or the follower. Entry timing is critical whether companies are concentrating on their home markets (new product/service launch) or are entering international markets (foreign market entry) using 'sprinkler' entry strategy entering simultaneously multiple markets or by using 'waterfall' entry strategy entering lead countries first and then subsequent national entries (Ohmae, 1985, Kalish, et al., 1995).

Selecting correct entry timing requires understanding and anticipation of evolutionary path of product and technology life cycle. The takeoff point is especially important since nascent markets enter mainstream customer markets and customer characteristics and segments change drastically after this particular point (e.g. Mahajan, Muller and Srivastava, 1990, Mahajan and Muller, 1998). The change in customer characteristics poses new sets of needs and requirements that need to be responded through product development and overall operations (e.g. Mahajan et al., 1990, Moore, 1999). However, the anticipation of takeoff point is difficult since the timing of the takeoff point is dependent on e.g. market dynamics and characteristics, product category, competitive dynamics, number of competitors and pricing decisions (Golder and Tellis, 1997, Klepper, 1997, Agarwall and Bayus, 2000).

Dynamics of takeoff point is of special interest since if companies were able to anticipate takeoff point they would be prepared to plan their operations like product development, manufacturing, distribution etc. to respond to rapidly growing markets. This article builds the existing knowledge base by explicitly considering the dynamics of the takeoff point from the cross-national point of view. The paper focuses on three distinct questions:

- Is it possible to determine the takeoff point, and hence demonstrate the takeoff phenomenon, in the sales data of the end-user adoption of analogue and digital cellular telephone technologies?
- If there is a takeoff phenomenon, then is there a lead-lag effect in the takeoff, i.e. adoption takeoff time of lagging countries is shorter than the leading countries?
- If this lead-lag effect is present what is its pattern and how strong is it?

RESEARCH METHODOLOGY

This research studies the adoption of analogue and digital cellular telephone technology globally. Analogue radiotelephone services with manually operated exchanges have been neglected and only fully automatic analogue mobile telephone systems are included. Data used in the study was the yearly cumulative number of analogue cellular subscribers in each national market. Therefore, the study concentrates on the category level of the analogue and digital cellular telephone technology.

The main source for data has been International Telecommunication Union (ITU). Other sources include International Engineering Consortium (IEC), equipment vendors, telecommunication operators and trade journals and magazines like Telecommunications, Communications International, and Cellular Business etc. Multiple data sources were used to build sound establishment of the actual launch year of the cellular telephone service.

Launch year is the earliest year verified by multiple sources if the sources have stated different launch dates. Also subscriber data has been checked to see whether there have been actual subscribers on the earliest years. Usually differing launch dates are results of interpreting piloting of networks differently. However, for the purposes of this study, the interpretation is that the national level adoption of the technology and usage information accumulation starts when the first exposure to the information considering the local usage of the technology is available, whether a pilot or a full commercial launch. Therefore, it is appropriate to use a launch year that first exposed markets to the technology.

In order to reliably to determine possible takeoff points at least three years of data was required after introduction.[1] Therefore, effectively national introduction after 1998 were not included in the analysis since the data spanned until 2000.

Based on the discussion above, the total data set of time series for the present study included technology adoption of analogue cellular telecommunications for 142 countries and digital cellular telecommunications for 169 countries.[2]

From the total data set 2 countries in analogue category and 39 countries in digital had to be rejected in the grounds that they had too few data points (launched 1998 or after).

If countries had experienced extremely low penetration they also had to be treated cautiously (e.g. Dekimpe et al., 1998). This is due to the volatile nature of technology life cycle in its introductory phase; at low adoption levels small changes have significant impact on cumulative dynamics that does not reflect the actual change in overall dynamics. A cut-off criterion to control this and exclude countries from data sets has traditionally been fixed 3-5% penetration. However, in the research these countries were not disqualified but rather countries with lower than 3 % penetration were estimated cautiously. Since takeoff can take place earlier than this penetration point the time series were studied further to understand whether the takeoff had occurred. If the dynamics was very volatile (increasing and decreasing rate of growth

[1] Three data points translates to at least one pre- and/or post-takeoff points, in addition to actual takeoff point.

[2] 'Country' is a UN and ITU classification that loosely treats some regions as countries.

in cumulative subscriber time series) the country was neglected from the study. But if the dynamics clearly showed a pattern, even at low penetration levels, it was included in the study. 22 countries in analogue technology and 3 countries in digital had to be neglected in the study due to the lack of adoption and/or unclear dynamics resulting from low volumes.

As a last measure to clear the final data set countries growing at constant linear rate were rejected from the study. Naturally the takeoff phenomenon could not be verified in these countries. 24 countries in analogue technology category and 5 countries in digital technology category had to be rejected because of this criterion.

After controlling for the above mentioned discrepancies there were 94 countries in analogue technology category and 122 countries in digital technology category and these time series were included in the further analysis.

Once the final data set was ready the study proceeded to determine the national takeoff points and analyze possible lead-lag effect in cross-national technology life cycle. In order to reliably and consistently determine takeoff points in time series the study used a similar discrimination analysis procedure that has been used by Gort & Klepper (1982) and Agarwal & Bayus (2000). The discrimination procedure used consisted of three steps. First, data series are examined to find whether or not they exhibit clearly 'hockey-stick' type of behavior i.e. takeoff point has face validity and determination is self-evident. Secondly, if further analysis is required, time series for cumulative number of subscribers, non-cumulative number of subscribers and percentage increase of subscribers were studied to identify data points that clearly belong to pre- and post-takeoff categories (categories 1 and 3, respectively). This left N consecutive data points in the possible takeoff period "in-between" pre- and post-takeoff, denoted by $x_1,x_2,x_3,\ldots,x_N$ (category 2). Next the data points in the category 2 were divided to pre- and post-takeoff points. Therefore, the discrimination analysis of points $x_1,x_2,x_3\ldots,x_N$ was carried out to find a point x_j that divided a first category of data points to $x_1,x_2,\ldots,x_j$ belonging to the pre-takeoff period and a second category of data points $x_{j+1},x_{j+2},\ldots,x_N$ belonging to the post-takeoff period. To discriminate data points in the category 2 discrimination analysis used the following procedure.

1. For each j=1,2,3,…,N we compute averages that represent the discrimination factors, $d_1(j)$ and $d_2(j)$

$$d_1(j)=\frac{\sum_{i=1}^{j} x_i}{j} \tag{1}$$

$$d_2(j)=\frac{\sum_{i=j+1}^{N} x_i}{N-j} \tag{2}$$

2. A data point j to be qualified as a possible takeoff point its discrimination factors have to fulfill following criteria to be eligible

$$|d_1(j) - \mu_1| \leq \left|\frac{\mu_1 - \mu_2}{2}\right| \tag{3}$$

$$|d_2(j) - \mu_2| \leq \left|\frac{\mu_1 - \mu_2}{2}\right| \tag{4}$$

where μ_1 and μ_2 are the means in the categories 1 and 2, respectively.

3. If there are no data points j to satisfy the criteria of equations 3 and 4, then all the data points in category 2 are classified as pre-takeoff points. If there are multiple data points j satisfying the criteria A1 and A2, then a data point j that maximizes $|d_1(j) - d_2(j)|$ is selected from this set.

This resulted in determination of whether there is a takeoff point in time series and if so which point it is.[3]

The strategy to investigate the lead-lag effect in the national takeoff times is to study standard OLS linear regression results between lag times and takeoff times between countries regression model taking the formulation [4] Also the graph of the lead-lag

[3] Other possibilities to determine takeoff point would have been standard discrimination analysis or adopter category determination from diffusion model (Mahajan, Muller and Srivastava, 1990). These however have certain restrictions that inhibit their usage. Discrimination analysis in order to be reliable would have required more data points (in essence yearly data was not sufficient to reliably determine different categories). Also adopter category determination produces reliable results only when the time series have more frequent points than yearly data. Hazard rate estimates were also neglected since they would have introduced judgmental element into the estimation procedure (Dekimpe et al., 2000).

[4] Following procedure of Takada and Jain (1991) in their study of lag time effect in the differences between national diffusion imitation coefficients.

effect in takeoff timing was analyzed. The standard regression model is presented in Eq. 5.

$$y_{ijk} = \alpha + \beta x_{ijk} + \mu_{ijk} \quad (5)$$

Here y_{ijk} is the takeoff time and x_{ijk} is the time lag from the first international introduction for countries i and j and for technology k. α and β are regression parameters and μ_{ijk} is a random disturbance term. In addition to this, also descriptive statistics of the takeoff times with each lag time was studied to gain additional insight on the possible dynamics of the lead-lag effect.

EMPIRICAL RESULTS

In the first phase of the research the inspection of time series revealed that the takeoff point was evident in 66 data series for analogue and in 81 data series for digital. These represent 70.2 % and 66.4 % of the total data sets, respectively. This highlights the existence of a clear 'hockey-stick' or 'elbow-shaped discontinuity' dynamics in majority of national markets. Figure 2 is an example of this type of dynamics in technology life cycle.

[Insert Fig. 1 about here]

The existence of the discontinuity at the takeoff point is one possible reason for the failure of the earlier studies to fit diffusion models into wireless telecommunications subscriber data. The large proportion of 'elbow-shaped' life cycle dynamics also reflects the discontinuous nature of technology adoption. There seems to be clear-cut differences in dynamics produced by earlier adopters versus later adopters already at very early phases of the adoption process.

The second phase of the determination of the takeoff point according to the procedure described above had to be carried out for 28 countries in analogue technology and for 41 countries in digital technology categories. These represent 29.8 % and 33.6 % of the total data sets, respectively. Although the discrimination procedure described incorporates judgmental element in ranking initial data points either to pre- or post-takeoff points, the procedure is not sensitive to produce wrong data points as takeoff points. As a part of the discrimination procedure the sensitivity to discriminate wrong takeoff point from the time series was tested by changing the definition of 'in-between' region. In this testing the takeoff point remained largely the same as the original one. If the identified takeoff point differed according to the 'in-between' region the takeoff point was studied based on the supporting time series like non-cumulative subscribers, percentage increase of subscribers and penetration time series. These data reveal peaks in non-cumulative and percentage change time series that are characteristic to the takeoff point. Therefore it was possible to discriminate even these difficult takeoff points unambiguously.

Tables 1 and 2 present the Pearson's correlation for both analogue and digital technologies. The Tables clearly suggest that there exists a linear relationship between lag time and length of takeoff time i.e. that there is a lead-lag effect. Further the correlations suggest that the lead-lag effect is indeed positive i.e. length of takeoff time decreases the longer the lagging time is.

[Insert Tables 1 and 2 about here]

The estimated regression model for the lead-lag effect in national takeoff timing for analogue and digital technologies are presented in Tables 3 to 6.

[Insert Tables 3 – 6 about here]

As can be seen from the tables the results confirm that the lead-lag effect is indeed present in the national takeoff timing, i.e. later countries have significantly shorter takeoff times of the national launch of technology than leading countries (parameter β is -0.209 for analogue and -0.234 for digital technology). However, linear regression models also suggest that more variables are needed to fully explain the difference in the length of takeoff times (R^2 is 0.158 for analogue and 0.098 for digital technology).

Figures 2 and 3 present graphical representations of lead-lag effect and also average takeoff times as a function of the length of the lag time.

[Insert Fig. 2 and 3 about here]

From the figures it can be interpreted that especially for analogue (1^{st} generation technology) the lead-lag effect seems to be rather strong (average takeoff time declines quite steadily). The same lead-lag effect is also present in average takeoff times of digital technology, although to a smaller extent.

The distributional properties of the takeoff times were also analyzed in order to further reveal the dynamics of lead-lag effect in cross-national takeoff timing. Standard deviation stays in the same region for all lag times, although the mean declines, for both technologies. This suggests greater variation of takeoff times with lag times. However, the small number of cases in each column makes it hard to interpret and make generalizations based on the data. One of the reasons for this might be that as the lead-lag effect increases more and more countries experience takeoff in their first year after introduction.

[Insert Table 7 – 8 about here]

The results clearly support the existence of a lead-lag effect in cross-national technology life cycle. However, more variables are needed in order to model and explain the dynamics of declining takeoff times as the technology and businesses surrounding it evolve.

DISCUSSION

Usually in wireless telecommunications technologies are not introduced simultaneously in all markets. Main reasons for this are regulatory boards and agencies regulating market entries. And even though market entry might be granted at the same time different players enter market at differing times. Therefore, national market launches are depending on political processes for the actual technology adoption to start. This naturally has its own implications for the life cycle dynamics. Also the large number of parties and interests surrounding launch decisions make the life cycle dynamics challenging to explain and model. However, even in this kind of complex environment the lead-lag effect is present in the lengths of national takeoff times.

Wireless telephone networks require a lot upfront investment in national level. This leads to difficulties in interpreting and modeling technology life cycle dynamics if the time paths of national investments differ greatly. National roll-outs may first be in big cities, and then gradually elsewhere and this phased roll-out is country specific taking into consideration e.g. political aspects, economic activity, distribution of income etc. Some of these difficulties were highlighted in the large number of rejected countries which didn’t have either enough data points or had awkward dynamics like increasing-decreasing cumulative subscribers. Further, installed base (i.e. availability of traditional landline telephony) has impact on the national adoption of substituting (at least partly) cellular technology.

Practical results from the study suggest that companies can expect a sooner takeoff of technology life cycle from later adopting countries. However, the results also suggest that there is a need to be cautious about lead-lag effect. It may not be as straight forward as traditionally thought and there are also multiple other (major) variables that need to be considered when anticipating the start of growth phase in technology life cycle. Especially interesting the results are in the light of market entry timing and its selection and determination. A company considering entry to a national market that is lagging in the global technology introduction can expect rather rapid takeoff of technology. This creates a timetable for the ramp-up of operations that can be built from experiences from countries that are leading in the technology adoption.

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FIGURES AND TABLES

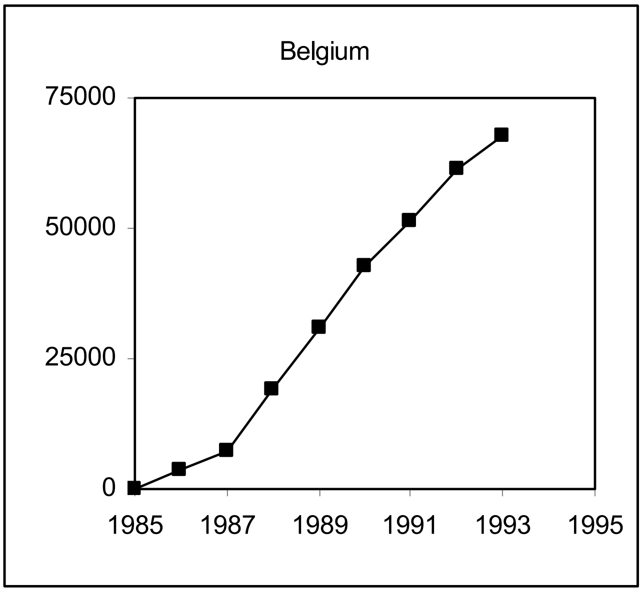

Figure 1. Cumulative adoption of analogue technology in Belgium as an example of an existence of a clear discontinuity at the takeoff point.

Table 1. Pearson correlations between takeoff time and launch lag for analogue technology.

	a_Takeoff time	a_Launch lag
a_Takeoff time	1	-0.408
a_Launch lag	-0.408	1

Table 2. Pearson correlations between takeoff time and launch lag for digital technology.

	d_Takeoff time	d_Launch lag
d_Takeoff time	1	-0.313
d_Launch lag	-0.313	1

Table 3. Regression analysis between takeoff time and launch lag time, analogue.

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.408	0.167	0.158	1.68
Predictors: a_Launch lag			

Table 4. Regression analysis between takeoff time and launch lag time, analogue.

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	6.322	0.491		12.872	0.000
a_Launch lag	-0.209	0.049	-0.408	-4.289	0.000
Dependent Variable: a_Takeoff time					

Table 5. Regression analysis between takeoff time and launch lag time, digital.

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.313	0.098	0.091	0.99
Predictors: d_Launch lag			

Table 6. Regression analysis between takeoff time and launch lag time, digital.

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	3.378	0.209		16.180	0.000
d_Launch lag	-0.234	0.065	-0.313	-3.612	0.000
Dependent Variable: d_Takeoff time					

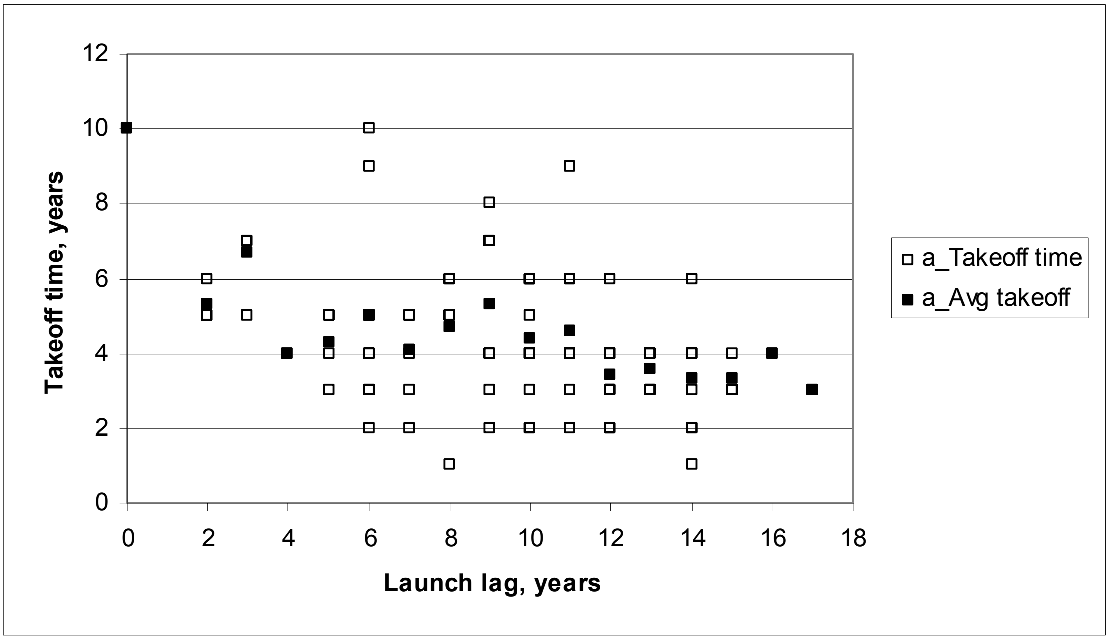

Figure 2. A representation of takeoff time as a function of launch lag (analogue technology).

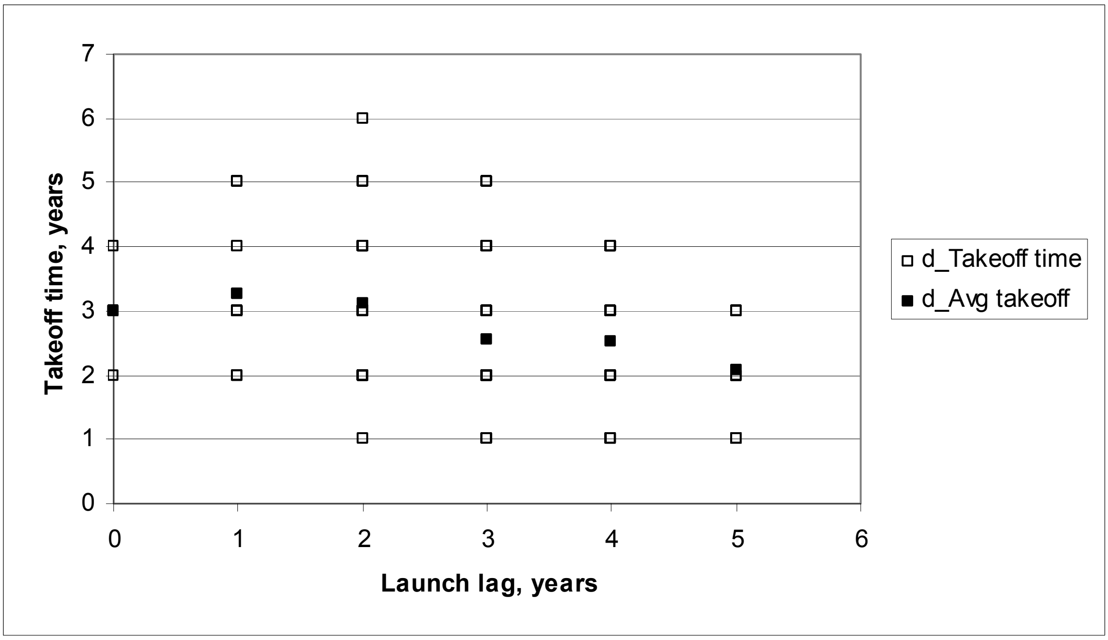

Figure 3. A representation of takeoff time as a function of launch lag (digital technology).

Table 7. Statistical analysis of takeoff times, analogue technology.

a_Launch lag	Mean	N	Std. Deviation	Std. Error of Mean
0	10	1	-	-
2	5.33	3	0.58	0.33
3	6.33	3	1.15	0.67
4	4	1	-	-
5	4.25	4	0.96	0.48
6	5	10	2.58	0.82
7	4.14	7	1.21	0.46
8	4.67	6	1.86	0.76
9	5.25	8	2.25	0.8
10	4.36	11	1.57	0.47
11	4.6	10	1.96	0.62
12	3.27	11	1.19	0.36
13	3.57	7	0.53	0.2
14	3.14	7	1.68	0.63
15	3.33	3	0.58	0.33
16	4	1	-	-
17	3	1	-	-
Total	4.35	94	1.83	0.19

Table 8. Statistical analysis of takeoff times, digital technology.

d_Launch lag	Mean	N	Std. Deviation	Std. Error of Mean
0	3	8	0.53	0.19
1	3.25	12	0.97	0.28
2	3.13	24	1.23	0.25
3	2.55	31	1.03	0.18
4	2.52	33	0.94	0.16
5	2.07	14	0.73	0.2
Total	2.7	122	1.04	0.09