

MARKET POTENTIAL DYNAMICS AND DIFFUSION OF INNOVATION: MODELLING SYNERGY BETWEEN TWO DRIVING FORCES

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ABSTRACT. The presence of a slowdown in new products' life cycle has recently received notable attention by many innovation diffusion scholars, that have tried to explain and model it on a typical dual-market hypothesis. In this paper we propose an alternative explanation, based on the co-evolutionary model by Guseo and Guidolin, where diffusion results from the synergy between two driving forces: communication and adoption. We test the model on sales data of some pharmaceutical drugs presenting a slowdown in their life cycle. A deeper analysis of communication and adoption interaction, based on the likelihood ratio order can inform on which of the two had a driving role in early diffusion.

1 INTRODUCTION

Some recent literature on innovation diffusion has followed the idea that the market for new products needs to be divided into two major segments, usually termed "visionaries and pragmatists" (see Moore (1991)), "early market and main market" (see for instance Karmeshu and Goswami (2001), Vakratsas and Kolsarici (2008)), "influentials and imitators" (see Van den Bulte and Joshi (2007)). In particular Moore, suggested that the market for innovations is initially just represented by early adopters and that the main market develops in a second stage of diffusion. Early and main markets are different in their attitude and expectations towards novelties and this difference may result in a precise separation between the two. Such separation has been theorized as a possible explanation of the slowdown pattern –also known with minor differences as chasm, saddle or dip– that many diffusion processes show when, after a rapid takeoff, product's sales reach an initial peak followed by a decline –whose length and depth may vary– and eventually by a resumption that may exceed the initial peak. Another model proposed by Guseo and Guidolin (2009) shows that a slowdown in diffusion may emerge as consequence of the sum of "two densities", i.e. the existence of a "dual-effect" in market evolution. However, the approach is radically different, since such a duality does not come from a separation into segments of adopters, rather on an interpretation of diffusion as composed of two distinct, yet co-evolving processes: communication and adoption. In particular, communication dynamics are seen as determinants of the market potential, whose structure is not fixed, but generated through time as function of the spread of knowledge about an innovation. The "dual-effect" modelling allows the recognition of a more interesting aspect than the pure determination of a slowdown, expressing a dynamic ranking between the two co-evolving processes with different managerial implications.

The paper is organized as follows. In Section 2 we present some definitions and basic properties of Guseo and Guidolin (2009) co-evolutionary model with a particular specification of a dynamic market potential. In Section 3 we consider two different pharmaceutical drug diffusions in Italian geographic areas that exhibit slowdowns and saddle effects well-recognized by previous model. In Section 4 we propose a natural decomposition of model density that allows a simple interpretation of the drivers in evolution due to main effects exerted by communication and adoption forces. *Likelihood ratio order* explains the different time position of these forces.

2 CO-EVOLUTION OF MARKET POTENTIAL AND DIFFUSION

A recurring assumption in the above mentioned mixture models is the existence of different local market potentials. In Guseo and Guidolin (2009) this discrete unnecessary taxonomy has been overcome through a special Cellular Automaton description whose aggregate mean-field approximation, in continuous time, yields

$$y'(t) = m(t) \left\{ -r_s \frac{y(t)}{m(t)} + \left(p_s + q_s \frac{y(t)}{m(t)} \right) \left(1 - \frac{y(t)}{m(t)} \right) \right\} x(t) + y(t) \frac{m'(t)}{m(t)}, \quad (1)$$

where $y'(t)$ represents instantaneous adoptions at time t , $y(t)$ denotes the corresponding cumulative adoptions, p_s and q_s are the usual Bass like parameters depicting innovation (external) and imitation (internal) effects, r_s accounts for a possible decay effect due to not retained adoptions. In this model a particular attention is devoted to a general representation of the market potential via a non-negative flexible function $m(t) \geq 0$. We highlight that it is not a function of a special family. A characteristic claim in Equation (1), the “self-reinforcing” term, $y(t) \frac{m'(t)}{m(t)}$, emphasizes the instantaneous variations in $y'(t)$ due to a collective or inertial movement of global market potential. An expanding $m(t)$ induces a benefit in instantaneous adoptions and, vice versa, a declining $m(t)$ implies a shrinkage of them. Under a constant market potential, $m(t) = m$, the self-reinforcing effect is absent. Equation (1) is based on the modification over time of uniform dynamics due to *exogenous interventions* effects (source of external heterogeneity) during the diffusion process. A similar approach is developed in Bass *et al.* (1994) in the Generalized Bass Model (GBM) with an assumed fixed potential m . This flexible context is modelled through a multiplicative intervention function, $x(t)$, whose neutral level is $x(t) = 1 \forall t$, which may incorporate exogenous factors, like marketing mix strategies, different political regulations or incentive measures. Notice that function $x(t)$ only exerts its effect on the first component of Equation (1), which is a function of the future, and not on the self-reinforcing term, which only depends on the past. The original GBM is a particular sub-model in Equation (1) because two special constraints apply: the decay parameter is excluded, $r_s = 0$, and the market potential is constant, $m(t) = m$.

Equation (1) defines a nested co-evolutionary model as a special non-autonomous Riccati equation. Its closed form solution (see, Guseo and Guidolin (2009)) is

$$y(t) = m(t) \frac{1 - e^{-D_s \int_0^t x(\tau) d\tau}}{\frac{1}{s^{\prime 2}} - \frac{1}{s^{\prime 1}} e^{-D_s \int_0^t x(\tau) d\tau}}, \quad D_s = \sqrt{(q_s - p_s - r_s)^2 + 4q_s p_s} > 0, \quad (2)$$

where ${}_s r_i = -(q_s - p_s - r_s) \pm D_s / (-2q_s)$, $i = 1, 2$, with ${}_s r_2 > {}_s r_1$.

Notice that function $m(t)$ may be modelled according to different perspectives. In Guseo and Guidolin (2009) we can find a special proposal based on a formal description of knowledge dynamics regarding a specific innovation, and interpreted as a growing network constituting a basic precursor to market potential. Communication dynamics are represented by a Network Automata whose mean-field approximation, in continuous time, is proportional to an autonomous Riccati equation, namely,

$$v'(t) = -(q_c + w_c)v^2(t) + (q_c - p_c - e_c)v(t) + p_c, \quad q_c > p_c > 0, \quad (3)$$

where p_c denotes the external or innovative component of the communication process while q_c and w_c represent positive and negative word-of-mouth effects and e_c is a decay effect representing the natural loss of information due to ageing. If we exclude e_c and w_c , we obtain a standard Bass model referred to network growth.

Without loss of generality, we can consider $h(t) = \sqrt{U} \sqrt{v(t)}$ as the number of *informed individuals*, which is proportional to $\sqrt{v(t)}$, so that we may assume $m(t) = K \sqrt{v(t)}$ as the actual market potential, where K is a free parameter useful for repeated adoptions.

If communication effects are *persistent*, i.e. with no decay effect, $e_c = 0$, and no negative word-of-mouth, $w_c = 0$, then we obtain

$$m(t) = K \sqrt{\frac{1 - e^{-(p_c + q_c)t}}{1 + \frac{q_c}{p_c} e^{-(p_c + q_c)t}}}. \quad (4)$$

The statistical implementation of model (2) may require alternative error structures. In a nonlinear regressive approach we consider a particular model for observations, $w(t) = y(t) + \epsilon(t)$, with an i.i.d. residual $\epsilon(t)$. A more realistic approach is based on ARMAX representation with a standard nonlinear estimation as a first step, which acts as ‘‘covariate’’ parallel to the autocorrelated residuals (see, for instance, Guseo and Guidolin (2009)).

3 PHARMACEUTICAL DRUGS’ DIFFUSION IN ITALIAN AREAS

In this section we present some applications of the Guseo and Guidolin (2009) model to the diffusion of some new pharmaceutical drugs, introduced in the Italian market in 2005. The data, provided by IMS Health, cover the period between August 2005 and July 2007 with a spatial disaggregation by areas. Pharmaceutical products appear an ideal candidate for modelling the co-evolution of communication and adoption, where the first usually precedes and pulls the second. However, this common order may be contradicted in some cases, where adoption dynamics have a driving role. A recent work on the diffusion of new drugs by Vakratsas and Kolsarici (2008) remarks that the market for pharmaceuticals is created from patients’ need for treatment, as diagnosed by physicians, and that this need will be unfulfilled if no prescription is available at the time of the diagnosis. Consequently, this will result in an accumulation of demand, prior to product launch. Thus, we may expect that a new drug, treating a severe pathology, will be characterized by a diffusion process where the accumulated demand of patients determines an early dominance of adoptions.

For simplicity and space reasons we only examine here the following two different configurations: “KEP–NordEst” and “LYR–Italy” or, more briefly, “KEP” and “LYR”. “KEP” has been launched in Italy in April 2005. The new active principle on which the drug is based, *Ketoprofen*, is commonly employed for treating pain and inflammations. In particular, the topical ketoprofen patch appears an effective and safe option for the treatment of painful inflammations. Based on the active principle of *Pregabalin*, “LYR” was initially approved for treating epilepsy (as adjunctive therapy), neuropathic pain and post-herpetic neuralgia pain, that is to treat pain caused by nerve damage due to diabetes and herpes zoster infection. In particular, Pregabalin is considered a valuable addition to the still-limited options to the treatment of neuropathic pain, proving to be effective in patients who have previously failed to respond to other active principles (e.g. Gabapentin). More recently, some studies have shown that Pregabalin is effective at treating chronic pain in disorders such as fibromyalgia.

We apply the model without exit rates (parameters $w_c = e_c = r_s = 0$) and exogenous interventions (function $x(t) = 1$),

$$w(t) = K \sqrt{\frac{1 - e^{-(p_c+q_c)t}}{1 + \frac{q_c}{p_c} e^{-(p_c+q_c)t}} \frac{1 - e^{-(p_s+q_s)t}}{1 + \frac{q_s}{p_s} e^{-(p_s+q_s)t}} + \varepsilon(t)}. \quad (5)$$

In Figures 1 and 2 we summarize the estimation results under a nonlinear least squares approach (Levenberg–Marquardt; see, for instance, Seber and Wild (1989)). “KEP” denotes an acceptable behaviour in “NordEst” area with a good NLS fitting, $R^2 = 0.999702$. “LYR–Italy” presents a mature life cycle with some evidence of market contraction. The NLS fitting is excellent, $R_1^2 = 0.99991$. Previous results highlight different dynamics in diffusion of new pharmaceutical drugs. In particular, we observe in both cases the presence of a slowdown in the earlier part of diffusion, with a quite pronounced saddle. This effect may be explained through an interaction between the variable market potential and the corresponding adoption process.

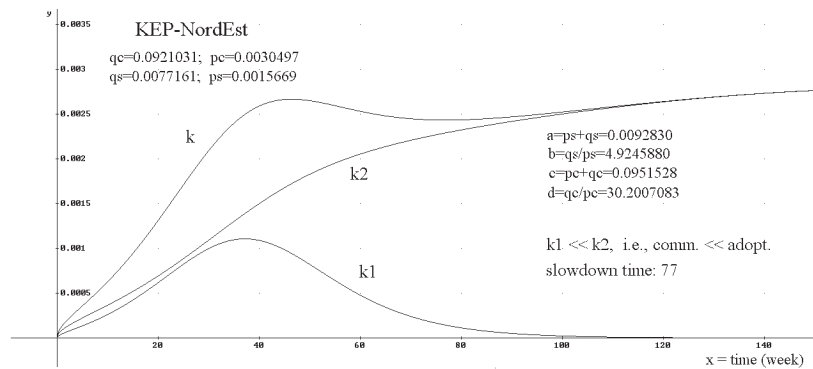


Figure 1. “KEP–NordEst”: two synergic components. Communication effort (k_1) is a precursor of adoption activity (k_2) for “KEP” in “NordEst” area of Italy. Data source: IMS–Health, Italy. Normalized weekly sold packages; period: 8/2005 – 7/2007.

4 SOME STATISTICAL ASPECTS OF A CO-EVOLUTIONARY MODEL

We may consider a simple reparameterization in Equation (5), i.e., $a = p_s + q_s$, $b = q_s/p_s$, $c = p_c + q_c$ and $d = q_c/p_c$, so that we obtain

$$w(t) = K \cdot \sqrt{\frac{1 - e^{-ct}}{1 + de^{-ct}}} \frac{1 - e^{-at}}{1 + be^{-at}} + \varepsilon(t) = K \cdot \sqrt{F(t)} G(t) + \varepsilon(t). \quad (6)$$

Under the usual internal unimodality assumptions on diffusion parameters, $0 < p_s < q_s$ and $0 < p_c < q_c$ or simply under the non-negativity of parameters p_c, q_c, p_s and q_s , we highlight that $K(t) = \sqrt{F(t)} G(t)$ is a probability distribution function.

Let us denote its density $k(t) = \partial K(t)/\partial t$ with a reduced notation, i.e.,

$$k(t) = \frac{1}{2} F(t)^{-1/2} G(t) f(t) + F(t)^{1/2} g(t) = k_1(t) + k_2(t), \quad t > 0, \quad (7)$$

where $f(t) = \partial F(t)/\partial t$ and $g(t) = \partial G(t)/\partial t$.

We may consider a normalization of non-negative functions $k_1(t)$ and $k_2(t)$ deriving two corresponding densities $\tilde{k}_i(t) = k_i(t)/K_i$ with $K_i = \int_0^\infty k_i(t) dt$, $i = 1, 2$. Suppose that a random variable X is associated to $\tilde{k}_1(t)$ and, similarly, a random variable Y to $\tilde{k}_2(t)$.

Definition. We say that Y is larger than X in *likelihood ratio order*, $X \leq_{lr} Y$, if X and Y have densities such that, for all $s \leq t$,

$$\tilde{k}_1(t) \cdot \tilde{k}_2(s) \leq \tilde{k}_1(s) \cdot \tilde{k}_2(t). \quad (8)$$

Notice that inequality based on $\tilde{k}_i(t)$, $i = 1, 2$ densities does not depend on the quantities K_1 or K_2 or their ratio. We can compare directly $k_i(t)$, $i = 1, 2$. Equation (8) states that $\tilde{k}_2(t)/\tilde{k}_1(t)$ or $k_2(t)/k_1(t)$ is increasing avoiding the special cases with vanishing denominators.

As a direct control, we can compute the likelihood ratios $\tilde{k}_2(t)/\tilde{k}_1(t)$ or $k_2(t)/k_1(t)$ for ‘‘KEP’’ obtaining an increasing function. This allows a simple interpretation: the effect associated to $k_1(t)$, i.e. the communication effect, has an earlier dominance in the evolution of this drug. Vice versa, the opposite diffusion structure of ‘‘LYR’’, with an earlier driving role pertaining to adoption forces, is denoted by a decreasing ratio. The direct use of the *likelihood ratio criterion* gives a strong answer to the order of basic components $k_1(t)$ and $k_2(t)$. Observing Figure 1 we see that for ‘‘KEP’’ the likelihood order confirms a predictable behaviour, according to which communication has a driving role, preceding and pulling adoptions. Instead, in the case of ‘‘LYR’’, depicted in Figure 2, we observe an explicit inversion, so that the adoption component appears to dominate the first part of diffusion. We believe that this difference in behaviour may be related to the nature of the drugs considered.

As we anticipated in Section 3, drugs developed for treating severe pathologies already have an accumulated demand at the time of their launch into market, so that an early growth of adoptions is to be expected: this exactly may be the case of ‘‘LYR’’.

‘‘LYR’’ has been originally developed for neuropathic pain, a symptom common to various pathologies extremely difficult to understand and to treat. The painful condition of patients affected by this problem, makes not surprising their continuous search for every possible solution. The use of antiepileptic drugs for neuropathic pain management begun with two

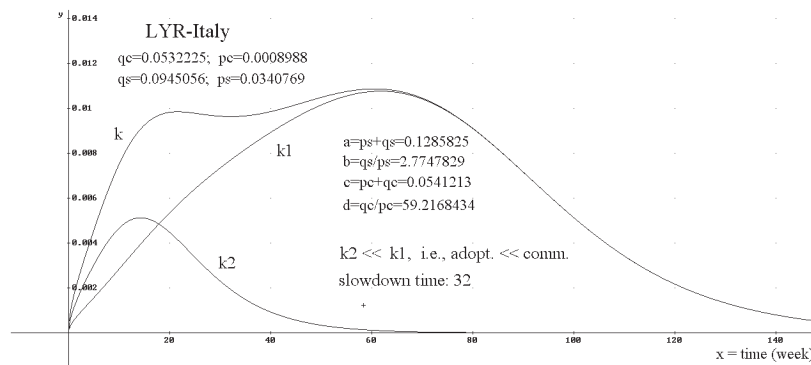


Figure 2. “LYR-Italy”: two synergistic components. Adoption activity (k_2) is a precursor of communication effort (k_1) for “LYR” in Italy. Data source: IMS-Health, Italy. Normalized weekly sold packages; period: 8/2005 – 7/2007.

active principles, *Carbamazepine* and *Gabapentin*: however, not always these drugs had the expected results, so that physicians and patients were waiting for the announced new generation of “neurostabilizers” drugs. When “LYR” was put into commerce there probably was an accumulation of demand for it: consistently, we have seen that adoption dynamics have a driving role in the first part of its diffusion process. Moreover, “LYR” exhibits a saturating life cycle probably due to its special formulation, which is based on a cumulative concentration with a natural delayed response, and to the cost of a prolonged therapy. These aspects may explain the reduction of adoptions and a return to *Gabapentin*.

On the other side, “KEP” is a drug that do not treat specific pathologies but is assumed as a precautionary measure to avoid more serious consequences. In these cases we may conclude that communication, both institutional and informal, has exerted its natural effect of stimulating adoptions through the generation of the market potential. “KEP” does not seem to have the characteristics of a really innovative product, so that in this case we argue that the pattern “first communication, then adoption” is explained by the simple need of promoting the new product, when put in commerce.

REFERENCES

- BASS, F.M., KRISHNAN, T., JAIN, D. (1994): Why the Bass model fits without decision variables, *Marketing Science* 13, 203–223.
- GUSEO, R., GUIDOLIN, M. (2009): Modelling a dynamic market potential: A class of automata networks for diffusion of innovations, *Technological Forecasting and Social Change* (Forthcoming).
- KARMESHU, GOSWAMI, D. (2001): Stochastic evolution of innovation diffusion in heterogeneous groups: study of life cycle patterns, *IMA Journal of Management Mathematics* 12, 107–126.
- MOORE, G. (1991): *Crossing the Chasm: Marketing and Selling Technology Products to Mainstream Customers*, Harper Collins Publishers, New York.
- SEBER, G., WILD, C. (1989): *Nonlinear Regression*, Wiley, New York.
- VAKRATSAS, D., KOLSARICI, C. (2008): A dual-market diffusion model for a new prescription pharmaceutical, *International Journal of Research in Marketing*, 25, 282–293.
- VAN DEN BULTE, C., JOSHI, Y.V. (2007): New product diffusion with influentials and imitators, *Marketing Science*, 26(3), 400–421.