Diffusion of Irrigation Technologies: The Role of Mimicking Behavior and Public Incentives

Marie-Estelle BINET*and Lionel RICHEFORT†

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Abstract

We develop a conceptual framework designed to assess the impact of public incentives on the diffusion process of modern, water-saving irrigation technologies. Diffusion patterns of the integral sprinkler cover system in the sugarcane sector of Reunion Island (France) are estimated using a sample of 110 farmers aggregated over the 1990-2006 period. We show that imitation is the main explanatory factor of the adoption dynamics. We also show that the characteristic diffusion path is not perfectly symmetric and is significantly affected by equipment subsidies.

Keywords: irrigation; technological change; Non-Linear Least Square estimates.

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1 Introduction

Water policy is an important topic in economic analysis due to the increasing problem of water resource scarcity [1]. In the farming sector, the technological trajectory of irrigation equipments may have a large influence on the demand

*CREM, Faculty of Economics, UMR 6211, CNRS, University of Rennes 1, France. E-Mail: marie-estelle.binet@univ-rennes1.fr

†CERESUR, Faculty of Law and Economics, University of Reunion Island, France and UMR G-EAU, CIRAD, France. E-Mail: lionel.richefort@cirad.fr

[1]See for example Berg and Lin (2008), Groom et al. (2008), García-Valiñas and Muñiz (2007) or Gaudin (2006) concerning recent results.

for applied water. In particular, the transition to new irrigation technologies could contribute to improve farmers' timing of water applications, and thus to save water [2] (Sunding and Zilberman, 2001). In this paper, we are interested in the following important question for water policy: once a modern, water-saving irrigation technology is introduced by one producer, what factors determine its adoption by the farming sector.

The analysis of the adoption of innovations by a social system has been deeply discussed by Rogers (1962). According to Rogers, innovations would be progressively adopted by the population, in such a way that drawing their diffusion rate over time would lead to an S-curve. This induces a bell-shaped frequency distribution for the number of adopters over time in which five types of adoption behavior have been defined [3]. The context of aggregate adoption behavior is thus characterized by two main processes: the "adoption process", related to private utility mechanisms, and the "diffusion process", defined as "the process of spread of a new technology within a region" (Feder et al., 1985; Feder and Umali, 1993). In this paper, we are interested in the diffusion process of a new irrigation technology in the sugarcane sector of Reunion Island (France).

The main model of technology diffusion focus on epidemic diffusion and the way in which imitative behavior could explain S-shape patterns of aggregate diffusion through the population of potential adopters over time (Griliches, 1957; Mansfield, 1961). Formally, a diffusion curve is defined as the solution to a differential equation of the form:

$$\dot{n}_t = f\left(n_t, \beta, N\right) \tag{1}$$

where n_t is a variable which denotes the fraction of the population having adopted the innovation at time t, β a parameter reflecting the likelihood of adopting the innovation (also called the *speed* of diffusion), N a parameter reflecting the size of the population who may eventually adopt the innovation (also called the *ceiling* of diffusion) and $f\left(\right)$ a function that determines the shape of the diffusion curve.

[2] See Richefort (2008), Chopart et al. (2006) and Fusillier (2006) for evidence concerning Reunion Island.

[3] Innovators, Early Adopters, Early Majority, Late Majority and Laggards.

Following Chow (1967), most of empirical research in this area has been concerned with the integration of economic parameters that change over time and may affect diffusion process speed and limitations (Glaister, 1974; Griliches, 1980; Bass, 1980; Horsky and Simon, 1983; Kalish, 1985). An interesting framework has been developed by Jarvis (1981), who showed that the diffusion of improved (fertilized grass-legume) pastures in Uruguay during the 1960-1980 period followed a logistic path in which diffusion speed and ceiling were influenced by beef and fertilizer prices. This framework has at times been applied to the specific area of modern irrigation technology diffusion. Results suggest a logistic diffusion curve, which may be affected by economic variables such as water price, crop yield price, and subsidy for irrigation equipment (Fishelson and Rymon, 1989; Dinar and Yaron, 1992).

This paper provides an original empirical contribution to this literature. Our data set offers a sample rarely seen in agricultural research. It includes a panel series of 110 farmers with observations in ownership of irrigation technologies before and after a significant change in the equipment subsidy rates. In addition to the data originality, we test several functional forms for fitting the real diffusion curve of the integral sprinkler cover system. Our analysis differs from traditional diffusion analyses in that both diffusion speed and ceiling are made a function of a subsidy rate [4].

This paper will be structured as follows. In Section 2, we present the conceptual framework. Section 3 presents the data and estimation strategy. In Section 4, the main empirical findings are discussed, and Section 5 concludes the paper by forwarding some recommendations for policy makers.

2 Conceptual framework

2.1 The diffusion path

Non-linear evolution in economic instruments may have an impact on both diffusion speed and ceiling (Kemp, 1997). Let N_t denote the number of farmers who may adopt the irrigation technology at time t, β_t the likelihood of adopting the new irrigation technology at time t and S_t the equipment

[4] See also Beers et al. (2007) to study the environmental impact of subsidies.

subsidy rate of the new technology at time t. We assume that the number of adoptions at time t is a function of variables n_t, β_t and N_t. Formally, a diffusion curve with endogenous diffusion patterns (speed and ceiling) is defined as the solution to a differential equation of the form:

$$\dot{n}_t = f\left(n_t, \beta_t, N_t\right) \tag{2}$$

Assuming that both β_t and N_t are a function of variable S_t, the diffusion curve $f\left(\right)$ is formally defined by parameters β, N, η and γ, through functions β_t and N_t written as follows:

$$\left\{\begin{array}{l} \beta_t = u\left(S_t, \beta, \eta\right) \\ N_t = v\left(S_t, N, \gamma\right) \end{array}\right. \tag{3}$$

Parameters η and γ denote the public subsidy impact on, respectively, diffusion speed and ceiling. We assume that an increase in the equipment subsidy rate will make farmers adopting faster the new irrigation technology: $du/dS_t = \eta > 0$. We also assume that an increase in the equipment subsidy rate will make more farmers adopting the new irrigation technology at the end of the diffusion process: $dv/dS_t = \gamma > 0$.

2.2 The diffusion curve

Previous work on irrigation technologies diffusion, and more generally on agricultural innovation diffusion, has mainly used the logistic diffusion curve.

In the pioneering work by Griliches (1957), the diffusion of new hybrid corn varieties is described by the logistic function with constant diffusion speed and ceiling. Formally, the logistic diffusion curve with constant diffusion patterns is defined as the solution to a differential equation of the form:

$$\dot{n}_t = \beta \frac{n_t}{N}\left(N - n_t\right) \tag{4}$$

Equation (4) states that the number of new adoptions at period t is equal to the number of potential adopters, $N - n_t$, multiplied by the probability of adoption, which is the product of the proportion of farmers already adopters at time t, n_t/N, and parameter β. It should be noted that while the probability of adoption increases over time, the number of new adopters decreases after a certain point (i.e. when $n_t/N = 0.5$) due to the decreasing number of non-adopters. The cumulative number of adopters is described by an S-shaped logistic curve, which asymptotically approaches the saturation level, N.

A classic alternative to the logistic model is offered by the Gompertz model, in which diffusion is slower at the start and end of the diffusion period (Chow, 1967; Lakhani, 1975; Dixon, 1980). Formally, the Gompertz diffusion curve with constant diffusion speed and ceiling is defined as the solution to a differential equation of the form:

$$\dot{n}_t = \beta n_t \left(\ln\left(N\right) - \ln\left(n_t\right)\right) \tag{5}$$

Equation (5) generates a slightly different sigmoid curve than Equation (4). The Gompertz curve is indeed positively skewed while the logistic curve is perfectly symmetric. The inflection point of the Gompertz curve occurs when 37 % of the ceiling has been reached (i.e. when $n_t/N = 0.37$). The relative diffusion rate, $\dot{n}_t/n_t$, does not decrease linearly with time. More precisely, the Gompertz model assumes that in equal small intervals of time the innovation loses equal proportions of its power of diffusion.

A classic extension of the logistic model is the Bass model, which enables drawing a distinction between innovative and imitative adopters by adding a parameter to the diffusion curve (Bass, 1969). Formally, the Bass diffusion curve with constant diffusion speed and ceiling is defined as the solution to a diffential equation of the form:

$$\dot{n}_t = \left(\delta + \beta \frac{n_t}{N}\right) \left(N - n_t\right) \tag{6}$$

Equation (6) states that the conditional probability of adoption depends on two parameters: parameter β, which may be interpreted as the coefficient of internal influence, and parameter δ, which reflects a source of information external to the diffusion process and may be interpeted as the coefficient of external influence[5] (Lekvall and Wahlbin, 1973). The term $\delta\left(N - n_t\right)$ on

[5]In our study, this source may include extension services and communication efforts

the right-hand side of Equation (6), which represents adoptions from farmers who are not influenced in their timing of adoption by the number of farmers already adopting, decreases progressively over time as the number of farmers who have not yet adopted at time t, $(N - n_t)$, continues to decrease.

3 Data description and estimation strategy

3.1 Data description

The data used in this study have been collected from a survey conducted in 2006; they were drawn by means of stratified sampling using a broader data set built by CIRAD (French Agricultural Research Center for International Development) in 2000 on farmers specialized in growing sugarcane. The strata were the spatial location of farmers and their water consumption levels.

[Insert Table 1 here]

Table 1 describes the evolution in sprinkler irrigation, the most widely spread irrigation technology in the irrigated area, for 110 farmers from 1990 to 2006 [6]. Sprinkler irrigation has mainly evolved from portable nozzle line or total cover system to integral cover system. This transition started slowly in the late 1980's followed by a progressive acceleration from the late 1990's until now. During the 1990's, agricultural and environmental policies moved towards more water-saving considerations and productivity-oriented considerations. This was essentially due to the introduction of new irrigated schemes in dryer areas. Then, in the 2000's, improving the productivity of sugarcane became the critical issue. This was motivated by a decrease in the surface and production of sugarcane facing urban extensions, a threat of closing the sugar factory and the renegotiations of the European policy about the sugar sector. This led institutions to allocate new resources for the adoption of more robust technologies (sprinkler with integral cover system and simplified

from local institutions to promote new irrigation technologies.

[6] Drip irrigation is located on only one third of the irrigated area as this technology have been promoted in dryer and windy areas in the late 1980's. The diffusion of this technology, after a slow start, is experiencing a progressive abandonment beginning in the late 1990's. This process is not studied here. See Richefort (2008) for more details.

extensions services). The basic idea was to provide incentives for a quick technological change for farms.

3.2 Estimation strategy

The estimation procedure follows two steps. We first estimate the simple logistic model with constant diffusion speed and ceiling. This model can be specified as follows [7] (Griliches, 1957):

$$Y_t = \alpha + \beta t + \varepsilon_t \tag{7}$$

where:
$Y_t = \ln\left(n_t/(N - n_t)\right)$
$\varepsilon_t \sim N\left(0, \sigma^2\right)$

Parameters α and β of Equation (7) can be estimated by Ordinary Least Squares. The ceiling is estimated by varying N parametrically from 70 % to 100 % of the proportion of farmers considered potential adopters. The equation yielding the highest R^2 is assumed to give the best conditional estimate for N (Jarvis, 1981). We also provide diagnostics for the presence of autocorrelation and analyse a first-order autoregression process [8].

At a second step, we estimate the logistic, the Bass and the Gompertz model by considering the potential effects of an increase in the equipment subsidy rate on diffusion speed and ceiling. We specify a functional relationship between diffusion patterns (variables β_t and N_t) and the equipment subsidy rate (variable S_t). Formally, considering that $S_t \in [0, 1]$, β_t and N_t may be specified as follows[9]:

$$\begin{cases} \beta_t = \beta + \eta S_t \\ N_t = N\left(1 - \gamma\left(1 - S_t\right)\right) \end{cases} \tag{8}$$

To take care of positive autocorrelation in the error term, we estimate the proportion of adoptions in each time interval. In this context, the logistic

[7] Solving Equation (4) gives the number of adopters as a function of time: $n_t = N\left(1 + \exp\left(-\alpha - \beta t\right)\right)^{-1}$ with α the constant of integration.

[8] See Greene (2000), pp. 531-533.

[9] Note that $\lim_{S_t \to 0} \beta_t = \beta$; $\lim_{S_t \to 1} \beta_t = \beta + \eta$; $\lim_{S_t \to 0} N_t = N - \delta N$ and $\lim_{S_t \to 1} N_t = N$.

model with endogenous diffusion speed and ceiling can be specified as follows (Kemp, 1997):

$$\Delta X_t = \beta_t X_{t-1} \left(X_t^* - X_{t-1} \right) + \varepsilon_t \tag{9}$$

where:
$\Delta X_t = (n_t - n_{t-1})/N$
$X_{t-1} = n_{t-1}/N$
$X_t^* = 1 - \gamma \left(1 - S_t\right)$
$\varepsilon_t \sim N\left(0, \sigma^2\right)$

Variable X_t denotes the proportion of farmers who have already adopted a new irrigation technology at time t and variable X_{t-1} denotes the proportion of farmers who adopted a new irrigation technology at time $t-1$. Parameters β , η and γ are to be estimated by adding a white noise (i.i.d.) error term on the right-hand side of Equation (9) [10].

To deal with the non-linear coefficients, we derived Non-Linear Least Squares estimates [11]. The empirical task then is to select the discerning specification of the dynamics of adoption. Several goodness of fit indicators are thus calculated. In practice, we first estimated the logistic model with constant β_t and constant N_t along with the three following variants: the logistic with β_t being a function of S_t, the logistic with N_t being a function of S_t and the logistic in which both β_t and N_t are a function of S_t. We also estimated the Gompertz model (and its three variants), specified as follows:

$$\Delta X_t = \beta_t X_{t-1} \left(\ln \left(N_t\right) - \ln \left(n_{t-1}\right) \right) + \varepsilon_t \tag{10}$$

and the Bass model (and its three variants), specified as follows:

$$\Delta X_t = \left(\delta + \beta_t X_{t-1}\right) \left(X_t^* - X_{t-1} \right) + \varepsilon_t \tag{11}$$

To produce the estimation, we eliminated from the sample those farmers who adopted the integral cover system after abandoning drip irrigation

[10] We also investigated the cases where β_t and N_t are a function of water price or output price. As expected in our context (almost constant prices), we obtained poor results which are not reported here. See Richefort (2008) for more details.

[11] Using both TSP and R statistical software to compare the results.

(less than 5 % of the total number of farmers in the sample), since these farmers could not qualify again for an equipment subsidy once they returned to sprinkler irrigation. All estimations were conducted over the 1990-2006 period.

4 Main empirical findings

The empirical results of the logistic model with constant diffusion speed and ceiling are listed in Table 2. The first important point to note is that the best estimate for the ceiling reflects closely the adoption of the integral cover system for sprinkler irrigation by farmers ($R^2 = 0.98$). Estimates of α and β are both significantly different from zero at the 5 % significance level and R^2 is maximized at $N = 0.83$. This implies that 83 % of farmers will eventually adopt, with 90 % of the ultimate ceiling being reached in 2011 and 99 % in 2018. The second important point to note concerns the presence of auto-correlated residuals. The Durbin-Watson statistic for Equation (6) is below 0.9, which does lead us to reject the null hypothesis that there is no autocorrelation at the 5 % significance level. A first-order autoregression process is then analyzed. As expected, it improves the estimation results. Evidence is provided by a much larger adjusted R^2 (0.99 compared to 0.98 previously), and log-likelihood (11.98 compared to 4.27 previously).

[Insert Table 2 here]

The results of the logistic model with constant diffusion speed and ceiling are given in Figure 1. It demonstrates this model can describe empirically the broad pattern of observed changes in ownership of the integral cover system for sprinkler irrigation during the period of investigation, with low values during the first years of diffusion and high values from 2000 to 2006. These results provide evidence that imitation, through word-of-mouth and bandwagon effects, is the main explanatory factor of the diffusion process.

[Insert Figure 1 here]

The empirical results of the logistic, the Bass and the Gompertz model with diffusion speed and ceiling specified as a function of the investment subsidy rate are listed in Table 3. Making β_t a function of S_t in the Bass and the Gompertz model gives better results than keeping β_t constant. Letting the number of potential adopters N_t be a function of S_t in the logistic and the Bass model also gives better results than keeping N_t constant. In each model however, making both β_t and N_t be a function of S_t barely improve the results. These results provide further evidence that the equipment subsidy rate is indeed a significant factor in the diffusion process of the integral cover system for sprinkler irrigation. They also suggest that the influence of the equipment subsidy rate is both through N_t, the number of potential adopters, and β_t, the diffusion speed.

[Insert Table 3 here]

The reported Durbin-Watson coefficients are above 1.9 and below 2.4 which does not lead us to reject the null hypothesis that there is no autocorrelation at the 5 % significance level. These values are higher than in the original regression, indicating that no serial correlation exists in the transformed estimated residuals. The reported R^2, adjusted R^2 and log-likelihood can be used to select the best specification form. The first model to emerge is the Gompertz model in which β_t is a function of S_t as this model gives the highest adjusted R^2, equal to 0.42. This value is consistent with previous works using the same framework (Kemp, 1997). The second model to note is the Bass model in which β_t is a function of S_t as this model provides both high R^2 (0.47), adjusted R^2 (0.39) and log-likelihood (43.56) compared to other models. The extra parameter δ included in the Bass model may slightly improve the results. In none of the estimations, however, is δ significantly different from zero at the 10 % level. These results show that farmers' sources of information for the integral cover system were mainly internal to the diffusion process [12].

The results of the Bass and the Gompertz model with $\beta_t = \beta + \eta S_t$ and $N_t = N$ are given in Figure 2. It shows that these models, by including

[12] These results may confirm that extension services and communication efforts from local institutions aimed at promoting new irrigation technologies, which were rather permanent during the diffusion period, have essentially been directed towards drip irrigation and sophisticated irrigation scheduling tools based on water balance models.

an investment subsidy capable of influencing diffusion speed, are able to describe the sudden rise in ΔA_t that appears in 2000 following an increase in the equipment subsidy rate. The effect of the non-linear change in farmers' adoption context due to the evolution in the subsidy rate is clearly illustrated. Furthermore, Figure 2 shows that the Gompertz model provides a sigmoid that is closer to the real diffusion curve than the Bass model, with lower values for ΔA_t at the start and end of the diffusion process.

[Insert Figure 2 here]

5 Conclusion

This article has developed a conceptual framework to allow understanding how farmers obtain information about modern, water-saving irrigation technologies and subsequently identifying the explanatory factors of adoption. We have estimated the logistic, the Bass and the Gompertz model in order to explain the diffusion of the integral sprinkler cover system in the sugarcane sector of Reunion Island (France), and this approach has included the possibility of assessing the impact of public incentives on diffusion speed and ceiling.

Results indicate that farmers' main sources of information for an integral cover system stem from word-of-mouth and bandwagon effects. In other words, imitation appears to be the main explanatory factor of the adoption dynamics. Results also show that the charateristic diffusion path does not draw a perfectly symmetric S-curve. An important explanatory factor of the diffusion process concerns economic incentives, as results demonstrate that an increase in the equipment subsidy rate has significantly affected diffusion patterns.

These results have important implications for policy makers. First, we have shown that the diffusion of an incremental innovation such as an integral cover system, which implies only a small change in irrigation practices for farmers already equiped with sprinkler irrigation, spontaneoulsy follows an S-curve. Moreover, we indicate that an increase in the equipment subsidy rate incites faster adoption of the new water-saving technology among farmers.

Finally, we show that diffusion is affected by non-linear changes in farmers' context of adoption.

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Figures and tables

Table 1: Adopting farmers and subsidy rate of an integral cover system for sprinkler irrigation in Reunion Island

Year	Proportion of new adopters[a]	Cumulated proportion of new adopters[a]	Subsidy rate[b]
1990	0.010	0.020	0.40
1991	0.017	0.038	0.40
1992	0.024	0.061	0.40
1993	0.035	0.097	0.40
1994	0.008	0.105	0.40
1995	0.020	0.125	0.40
1996	0.026	0.151	0.40
1997	0.026	0.177	0.40
1998	0.040	0.217	0.40
1999	0.016	0.233	0.40
2000	0.051	0.283	0.65
2001	0.100	0.383	0.65
2002	0.024	0.407	0.65
2003	0.036	0.443	0.65
2004	0.062	0.505	0.65
2005	0.092	0.597	0.65
2006	0.044	0.641	0.65

[a] calculated from a sample of 110 farmers (source: own survey).

[b] mean value of the subsidy rate per hectare (source: local institutions).

Table 2: Estimation results of the logistic model, 1990 – 2006

	α	β	ρ	N	R^2	adj-R^2	logLik	DW
(1)[a]	-540.79**	0.27**		0.83	0.98	0.98	4.27	0.80
	(19.82)	(0.01)						
(2)[b]	-504.39**	0.25**	0.39**	0.83	0.99	0.99	11.98	1.51
	(21.53)	(0.01)	(0.15)					

Projection of future adoption

	Year
$0.9N$	2011
$0.99N$	2018

** significant at 5 %, standard errors in parentheses

[a] $\varepsilon_t \sim N\left(0, \sigma^2\right)$

[b] $\varepsilon_t = \rho\varepsilon_{t-1} + u_t$ and $u_t \sim N\left(0, \sigma_u^2\right)$

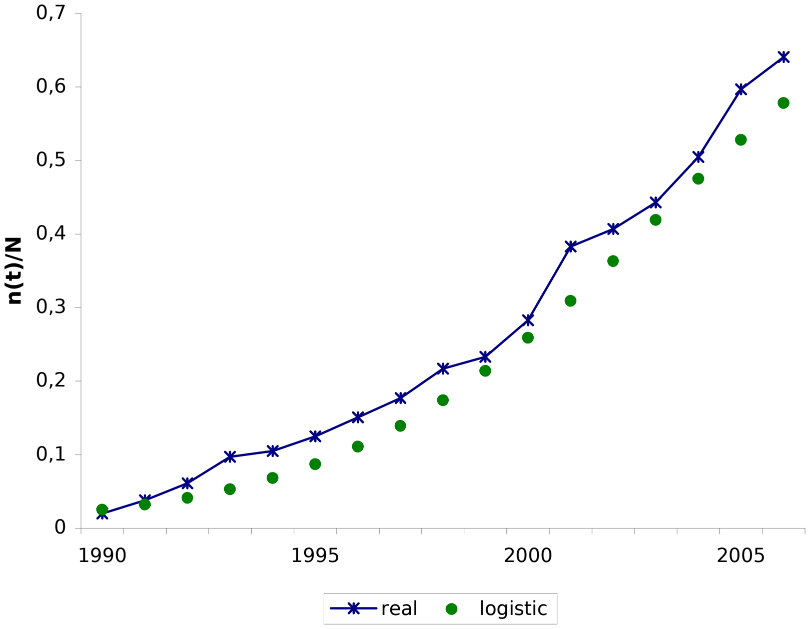

Figure 1: Model results for $\frac{n_t}{N}$ of the simple logistic model

Table 3: Estimation results of the logistic, the Gompertz and the Bass model, 1990 – 2006

	δ	β	η	γ	R^2	adj-R^2	logLik	DW
Logistic								
(1)[a]		0.24^{**}			0.35	0.35	41.90	2.22
		(0.03)						
(2)[b]		0.13	0.18		0.37	0.33	42.09	2.20
		(0.19)	(0.31)					
(3)[c]		0.43^{**}		0.66^{*}	0.40	0.36	42.52	2.11
		(0.17)		(0.35)				
(4)[d]		0.32	0.15	0.62	0.40	0.32	42.56	2.12
		(0.42)	(0.56)	(0.42)				
Gompertz								
(1)[a]		0.14^{**}			0.31	0.31	41.30	1.98
		(0.02)						
(2)[b]		-0.02	0.28^{*}		0.45	0.42	43.30	2.22
		(0.08)	(0.14)					
(3)[c]		0.09^{*}		-2.49	0.33	0.28	41.50	2.15
		(0.05)		(4.86)				
(4)[d]		-0.02	0.32	0.22	0.46	0.38	43.30	2.31
		(0.10)	(0.22)	(0.78)				
Bass								
(1)[a]	0.01	0.21^{**}			0.38	0.34	42.29	2.28
	(0.01)	(0.05)						
(2)[b]	0.02	-0.16	0.56		0.47	0.39	43.56	2.38
	(0.01)	(0.26)	(0.38)					
(3)[c]	0.01	0.38^{**}		0.67^{*}	0.43	0.35	42.94	2.21
	(0.02)	(0.17)		(0.36)				
(4)[d]	0.02	-0.15	0.66	0.40	0.48	0.36	43.68	2.34
	(0.02)	(0.37)	(0.55)	(0.66)				

** significant at 5 %, * significant at 10 %, standard errors in parentheses
[a] constant β_t and constant N_t
[b] $\beta_t = \beta + \eta S_t$ and constant N_t
[c] constant β_t and $N_t = N\,(1 - \gamma\,(1 - S_t))$
[d] $\beta_t = \beta + \eta S_t$ and $N_t = N\,(1 - \gamma\,(1 - S_t))$

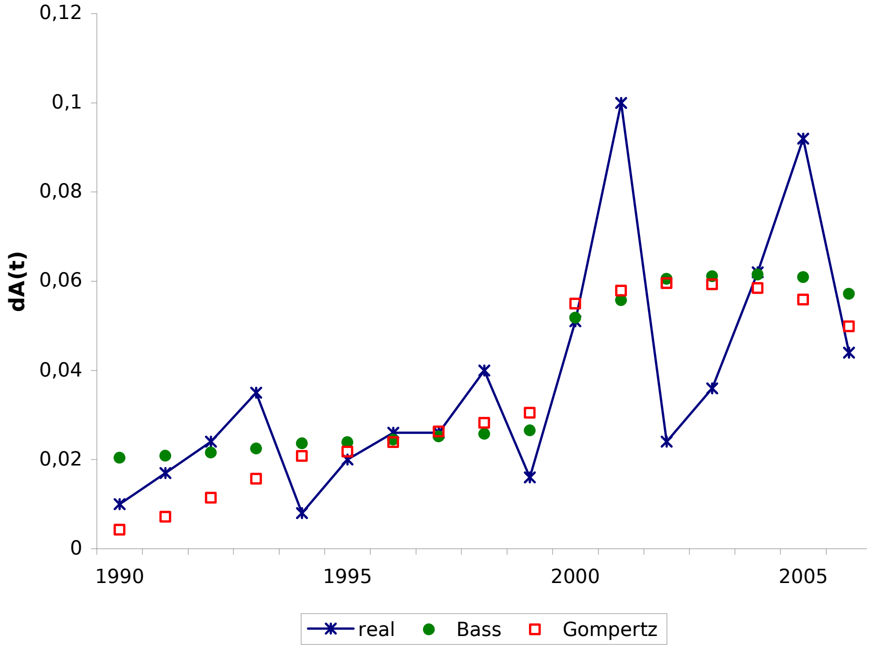

Figure 2: Model results for ΔX_t of the Bass and the Gompertz model with $\beta_t = \beta + \eta S_t$ and constant N_t