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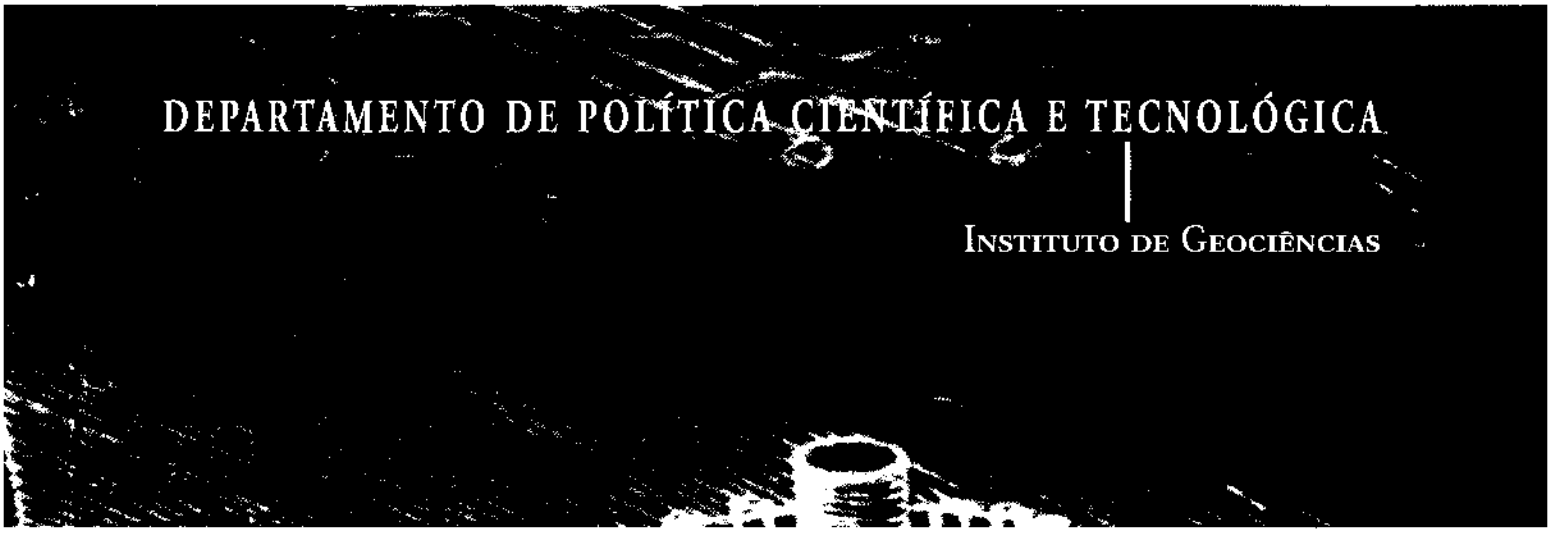

TEXTO PARA DISCUSSÃO
No. 28

THE SEARCH FOR A PERFECT SUBSTITUTE: TECHNOLOGICAL AND ECONOMIC TRAJECTORIES OF SYNTHETIC SWEETENERS, FROM SACCHARIN TO ASPARTAME (C. 1880-1980)

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DPCT/IG/UNICAMP
1999

DPCT
DEPARTAMENTO DE POLÍTICA CIENTÍFICA E TECNOLÓGICA
UNICAMP

THE SEARCH FOR A PERFECT SUBSTITUTE : TECHNOLOGICAL AND ECONOMIC TRAJECTORIES OF SYNTHETIC SWEETENERS, FROM SACCHARIN TO ASPARTAME (C. 1880-1980)[1]

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[1] Uma primeira versão deste trabalho foi apresentada no 12th International Economic History Congress, Session C-36 on "Sugar and Alternative Sweeteners in Historical Perspective", Madrid, agosto 1998.

ABSTRACT

Competition among alternative (and mutually substitutive) products, and among their respective producers, has been the rule in the markets for sweeteners from the very beginning of the 19th century, ever since the almost simultaneous appearance of beet sugar and of starch syrups. A landmark in this process was reached in 1879 with the discovery of saccharin, and the consequent advent of the synthetic sweeteners produced by the chemical and pharmaceutical industries. The number of these sweeteners has been increasing over time at an ever swifter pace, thanks to the progress of the biochemical and pharmacological sciences. While eight decades had elapsed between the "discovery" of beet sugar and that of saccharin, less than six were necessary for the upsurge of cyclamate - the second "artificial" sweetener - and less than three for that of aspartame - nowadays one of the most famous amongst them.

Together with HFCS (high fructose corn syrup), a biotechnologically obtained modern offspring of the starch syrups, these new products have been eroding considerably the world demand for sugar - both cane and beet. This is due not only to their lower costs and prices, but also - in several cases - to their flexibility and better performance in manufacturing processes. Within our industrial and urban societies, sweeteners in general are increasingly being consumed, not like in the past as essential foodstuffs by households, but as raw materials and inputs of industrial production. This has had obvious effects not only on the patterns of demand, but also on the rythm and direction of technical progress, and of the underlying scientific investigations.

Our paper will attempt to cope with these and other factors of the growing output and acceptance of synthetic sweeteners *vis-à-vis* the so-called natural ones. We do assume that such an evolution has been produced by something more than a simple change of consumer tastes and fashions.

INTRODUCTION

Although chemically unrelated to carbohydrates, and structurally unrelated to each other, synthetic sweeteners are neither independent of carbohydrates nor among themselves. First impressions and conventional wisdom are usually misleading guides for historical research. This can easily be perceived in the topic under analysis, whose development through time has generally been attributed to chance or to lucky events, not only by outsiders but even by specialists.[2] A closer look at the available data and informations, however, immediately dispels such claims.

In effect, nothing seems to be further from truth in the case of the discovery of saccharin, which was actually due to the American chemist Ira Remsen (1846-1927), despite the fact that it had been patented and commercially developed by a German one, Constantin Fahlberg (1850-1910). For a short time, both were associates at Johns Hopkins University in Baltimore, during the late 1870s, when ocurred the discovery, whose authorship they would bitterly dispute.[3] The former might have been attracted to the subject fortuitously, due to a "purely" scientific interest; but this, of course, was not the case with the latter, a sugar technologist by origin and a future sweetener industrialist in Germany [4], thanks to whom saccharin became a big business - not only in Europe, but also in the USA, where it gave origin to a firm of the importance of Monsanto Chemical Co.

Less than six decades later, fortuitous accidents seemed to characterize once again the discovery of cyclamates, at the University of Illinois in 1937. Having been patented by DuPont in 1940, and put on the market by Abbott Laboratories in the early 1950s, their sales were increasing steadily until the end of the following decade, when the American government banned their use for health reasons. This happened at a time when several other chemical and pharmaceutical companies had got involved in their manufacture,[5] including Monsanto.[6] Their participation was fundamentally due to the fast rising demand of a booming market, since cyclamates were "the major factor in launching the diet segment of the carbonated beverages industry", with its well-known products and trademarks.[7]

Having been banned in the USA, UK and Japan, cyclamates still linger in tens of other countries, consumed as additives in foods and beverages, as well as table-top sweeteners.[8] Their main market has been blending with other

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[2] As examples of the former, we may mention the statements by Roberts (1989), and of the latter those of Lipinsky (1995), p. 24.
[3] See on this the thorough and definitive account by Kauffman & Priebe (1978).
[4] An authoritative study of his business ventures can be found in the book by Merki (1993), ch.II.
[5] Cf. Kasperson & Primack (1986), pp. 72/73.
[6] Cf. Forrestal (1977), pp. 197/198.
[7] Cf. Miller (1987) p. 116, who was at the time vice-president of Royal Crown Cola Co. According to him, in the same article : "Such a large market for diet beverages provided a tremendous incentive to develop new sweeteners. Without this incentive, it is very doubtful that such large sums of money could have been justified for the development and testing of new sweeteners. The establishment of the low calorie food and beverage industry is the cyclamate legacy."
[8] Cf. Bopp & Price (1991), pp. 74-76 and 90.

sweeteners, particularly with saccharin, while some developing countries - like Brazil, China and Thailand - have become their major producers.[9] Within such circumstances, the advent of aspartame, in the mid-1960s, can only be perceived as a natural outcome.

It ocurred less than three decades after the discovery of cyclamates, and immediately before their definitive banning by the American sanitary authorities. When this got confirmed, aspartame was already on the spot for substituting them, and well prepared for reacting to both demand pull and cost push factors. And very probably not by coincidence, Monsanto soon again came back into the picture.[10]

Nevertheless, at least at the beginning, everything seems to have happened, once more, by sheer accident, only later giving place to more systematic activities. According to the account of one of the co-discoverers of aspartame,

> "In December 1965, James Schlatter was recrystallizing L-aspartyl - L-phenylalanine ester from methanol. The mixture bumped and spilled on this hand. Subsequently, when he licked his fingers to pick up a piece of weighing paper, he discovered the remarkable taste of this dipeptide ester. This event catapulted us into an intensive research program on aspartic acid-based sweeteners."[11]

Chance and coincidence can always be defended on strictly technical grounds, like in the statements below:

> "The original objective was the synthesis of gastrin tetrapepside to be used in a bioassay. Aspartylphenylalanine methyl ester (APM) was an intermediate (...) The taste of APM would not have been predicted from the tastes of the constituent aminoacids. L-aspartic acid is flat, while L-phenylalanine is bitter..."[12]

> "Although there have been numerous attempts to rationalize structure-taste relationships of synthetic and natural sweeteners, the resulting theories and associated formulations have lacked predictive value... ; that is, one cannot plan the synthesis of a compound unrelated to known sweet chemicals with any reasonable probability of turning up a sweet substance."[13]

But they surely never prevail in socieconomic terms, something which can be seen in these other statements of the same author:

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[9] Cf. LMC (1995), pp. 2 and 6.
[10] Cf. Higginbotham (1983), pp. 125/126; and McCann (1990), pp. 5/6. 75/76, 92 and 96-99.
[11] Cf. Mazur (1974), p. 159; similar statements have been repeated by him in Mazur & Ripper (1979), Mazur (1983), (1984) and (1991).
[12] Cf. Mazur (1974), *loc.cit.*.
[13] Cf. Mazur (1984), p. 3.

"What are my credentials for attempting to guess the future of synthetic sweeteners?

I was on the groundfloor of aspartame because, in 1965, James Schlatter, a chemist who worked for me, discovered the amazing taste of this rather simple molecule. Our employer, G. D. Searle & Co., decided to develop the material, and I have kept abreast of what has happened with synthetic sweeteners over the last 25 years. (...) It doesn't require much insight or expertise to realize that synthetic sweeteners are booming. Sales figures... (1984 : $ 568 million ; 1989 : $ 875 million) show this clearly. These impressive numbers certainly have benefited from the quality of aspartame's taste and from an inspired marketing strategy. However, people really want synthetic sweeteners and, when offered a product with reasonable properties, will rush to put down their money."[14]

In the remaining of this paper, we shall be discussing: (a) the main factors conditioning scientific research and development on synthetic sweeteners; (b) the increasing competition of these with sucrose (cane and beet sugar) on the one hand, and glucose syrups (mainly cereal starch-based) on the other; and (c) the possible outcomes of this competition, taking into account the economic power and efficiency of each involved group of interest.

CONDITIONING FACTORS OF RESEARCH AND DEVELOPMENT ON SYNTHETIC SWEETENERS

The predominance of sucrose in world consumption of sweetening products, both during the last centuries and up to our times, has contributed to transform it into the standard against which all other sweeteners are compared and measured. And, as we shall see in the next part of this exposition, it is also the market for sugar which has been used to quantify the sizes and shares of its competitors.

Such facts also explain why most research and development activities of (or for) the manufacturers of synthetic sweeteners have been directed towards the search and discovery of molecules presenting the closest possible sensorial and functional characteristics to sucrose. This trend has been compounded by the evolution of food legislation and sanitary controls which, at national and international levels, regulate the approval and certification for all products directly or indirectly destined to human consumption.

The referred technological and institutional factors, together with the fixed costs and the investments that they require, have become the main barriers to entry on the market of new sweeteners and of their respective producers. It is true that such barriers can always be circumvented by big firms through takeovers of smaller ones or by diversification of its activities, but this always requires a

[14] Cf. Mazur (1991), p. 313.

lot of available capital and some amount of technical expertise. And it does not preclude the risks and problems inherent to such moves, despite the fact, well observed by Nabors & Gelardi (1986) , that

> "The ideal sweetener does not exist. Even sucrose fails to fulfill many of the needs for sweetness. Indeed technological uses (e.g. pharmaceuticals) exist for which alternative sweeteners are superior to sucrose, regardless of other needs."[15]

It was exactly for these reasons that the first synthetic sweeteners (saccharin and cyclamates) were aimed at a partial substitution of sucrose, namely, in those segments of the market where either its price or its characteristics did not allow it to be consumed by all. Thus saccharin, at the end of the nineteenth century, besides being a sweetener for diabetics, also became the "sugar of the poor".[16] At the same time, and in the same way, those sweeteners began to be used in some pharmaceutical products and toiletries (like tooth-paste) as flavouring agents. A third and later application of them, also incompatible with sugar, was their use in dietetic products, as a way of reducing the caloric rate of certain foodstuffs and beverages.

Nowadays, however, this last objective seems to have gained a definite precedence over the others, with a consequent shift in research priorities. These are presently aimed at the search of a perfect substitute for sugar, a much more ambitious objective, but whose attainment may provide much larger rewards. Due to this, and once again according to Nabors & Gelardi (1986),

> "The ideal sweetener should be at least as sweet as sucrose, colourless, odorless and noncariogenic, with a pleasant, untainted taste and without a delayed onset or persistence in sweetness. The more a sweetener tastes like sucrose, the greater is its facility for use in food and beverage formulation."[17]

The development of a new sweetener, therefore, always includes a series of characteristics associated to:

a) <u>sensorial aspects</u> - like colour, taste, texture and aroma : besides the efects derived from its "natural" sweetness, the use of sugar allows to obtain special odours, colours and textures associated to some desired features of the products in which it is utilized;
b) <u>solubility in water</u>, a specially important aspect in the production of beverages, by granting an homogenous dilution of the sweetener;
c) <u>stability in different conditions of hydrogen ion concentration</u> (pH rates) - that is, resistance to acidity and to alkalinity;
d) <u>stability at different temperatures</u> - allowing the submission of the sweetened product to different kind of industrial processing (like heating, freezing and lyophilization);

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[15] *Op. cit.*, p. 5.
[16] Cf. Merki (1991), p. 71 and (1994), p. 194.
[17] *Op. cit., loc. cit.*

e) low chemical reactivity to other substances - thus avoiding undesirable secondary flavours;
f) stability through time - allowing a prolongued maintenance in stock of the product, both for manufacturing and for comercial purposes;
g) competitive costs and prices - and
h) non-toxicity - a fundamental feature of all products for human use, and - as we shall see below - a major restriction to the use of synthetic substances of any kind.[18]

The first condition for the obtention of a new sweetener is, of course, related to its taste. In this regard the contributions of science are still mainly empirical, due to the inexistence of a theory capable of explaining the complexity of the chemical and sensorial mechanisms which are responsible for the obtention of sweetness.[19] Karl Beck, among others, has stressed the great variety of the numerous synthetic chemicals having a sweet taste - a variety that makes it very difficult to formulate a theory capable of predicting the taste of new sweetener compounds.[20] This unpredictability of the sweetening power of chemical compounds has been a limiting factor to the rhythm of development of new products with the just enumerated desirable characteristics.

Another path in the development of new synthetic sweeteners, which has shown promising from the 1960s on, derives from the synergism of blends among different sweeteners, enabling a reduction of their individual quantities, and turning their joint use safer and more desirable than the isolated ones. Furthermore, these mixtures, in different proportions, also allow the obtention of the functional and sensorial characteristics desired for each product, according to the specificities of different foodstuffs and of their respective processing methods. Thus, for instance, the mixture of saccharin with cyclamates, which we have already mentioned, helped to reduce the former's bitter after-taste. More recently, and in very similar terms, the combination of aspartame with acesulfame-K (a sweetener produced by Hoechst) has increased the viability of the latter, also plagued by a disagreable after-taste, and, at the same time, gave to the former a greater stability through time. In other words, their synergistic relationship has contributed both to enhance their respective qualities and to decrease the defects of each compound alone.

Table 1 shows the rates of synergism obtained by blends of the products just named, in terms of their sweetening power (relative to sugar). Even more important, in economic terms, are the cost-effects of those mixtures, as shown on table 2. For such reasons, the concept of "multiple sweeteners", derived form these blends, has given origin to new alternatives in the search of "ideal" sweeteners.[21] This fact undoubtedly implies some significant consequences in

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[18] Compare this with what prevailed in the mid-1950s, ten years before the discovery of aspartame : "In order to be an acceptable sweetener of comercial utility, a substance must have sufficient sweetening power, be nontoxic, and be reasonably inexpensive to use." Cf. Ruhoff (1954), p. 559. For a contemporary systematization of these criteria, see, among others, DuBois (1991), pp. 2471-2473.
[19] Cf. Van der Wel *et alii* (1987).
[20] Cf. Beck (1974), pp. 138/139.
[21] Cf. Bakal (1986), pp. 328/329 ; Gelardi (1987).

terms of competition, by allowing the participation on the market of an ever growing number of different sweetener products and manufacturers.

Table 1
Rates of synergism (%) obtained by table-top blends of synthetic sweeteners

Sweeteners and blends	Original sweetening power	Expected sweetening power	Obtained sweetening power	Synergism
Saccharin	300	300	300	-
Cyclamates	60	60	60	-
Aspartame	200	200	200	-
Acesulfame-K	200	200	200	-
Saccharin + Cyclamates (1:10)	-	82	114	28
Aspartame+Acesulfame-K (10:1)	-	200	303	34
Saccharin+Aspartame (10:1)	-	275	500	45
Saccharin+Cyclamates+ Aspartame (2:15:5)	-	114	227	50

Source : LMC (1994), p. 3.
Observation: Numbers between parentheses in the first column refer to proportions of the blend.

Table 2
Costs of alternative sweeteners and blends for soft drinks manufacturers (World Prices 1994)

Sweeteners and blends	Cost per kg of sugar equivalent (US cents)	Relative to sugar (%)
Sugar	35	100
Saccharin	4	11,4
Cyclamates	25	71,4
Aspartame	33	94,3
Saccharin+Cyclamates (1:10)	7	20,0
Aspartame+Saccharin (1:3)	5	14,3
Saccharin+Aspartame+Cyclamates (2:5:15)	9	25,7
Aspartame+Acesulfame-K (1:1)	20	57,1

Source : LMC (1995), p. 4.
Observation: Numbers between parentheses in the first column refer to proportions of the blend.

The main institutional barrier to entry on the market of new sweeteners and of their respective producers is located in the food legislation and sanitary controls which regulate the approval and certification of all products directly or indirectly destined to human consumption. The main reference for the analysis of these public policy instruments has been the evolution of sanitary control legislation in the United States, whose economy is by far the largest market for all kind of sweeteners. And that evolution is pointing to the enactment of ever more rigid toxicological evaluation criteria and rules, which resulted, among others, in the formal banning of cyclamates and in the questioning of

saccharin's innocuity. The same trends have also been felt in the controversial approval process of aspartame.

American legislation in this field was consolidated sixty years ago, through the Federal Food, Drug and Cosmetic Act (FDCA) of 1938, which seeked to prohibit food adulterations nocive to human health. That law, however, did not require any demonstration of innoccuity of the foodstuffs employed by manufacturers. Two decades later, this loophole was supressed by the enactement of the 1958 Food Additives Amendment, which included among them all substances used intentionally and capable of becoming a component of any food, or of affecting its characteristics. Until that year, the Food and Drug Administration (FDA) - i.e. the federal agency responsible for its execution and fiscalization - had to prove the toxicity of any substance before prohibiting its use; but, from then on, the responsability of demonstrating the innocuity of new foodstuffs was transferred to their manufacturers.[22]

Similar orientations were subsequently adopted by other governments. In most countries, food additives have to comply with two essential requisites for the authorization of their use in foodstuffs : they need to be safe for human consumption, and necessary for the processing of manufactured food products. This means that, even if an additive presents the desired innocuity, its employment in foodstuffs may be prohibited whenever the manufacturer is unable to prove its functionality within the product's fabrication process.

The employment of intense sweeteners in foodstuffs has been justified by their capacity of reducing the caloric rate of food products, through the total or partial substitution of sugar and/or starch sweeteners. This attribute concerns primarily the diabetics, who have to limit their ingestion of carbohydrates present in them. Nevertheless, the main debate concerning the nutritional functionality of intense (and mainly synthetic) sweeteners has to do with their effectiveness in reducing or controlling human body-weight.

Up to now, the numerous tests made with this purpose did not present any conclusive results. According to M.F. Moyal, for instance, the nutritional effect of such sweeteners on appetite is quite complex :

> "*Il peut être différent d'un édulcorant à autre, d'une concentration à autre, d'un mode d'administration à autre. Par contre, en ce qui concerne la compensation alimentaire, les résultats obtenus par les différents chercheurs sont plus concordants.*"[23]

According to this author, the results of nutritional studies converge to the observation that human organisms tend to compensate the caloric reduction of some meals by way of a complementary ingestion of food some hours, or some days, thereafter. Due to this, the reduction of body-weight through the reduction of calories in diets by the use of intense sweeteners has yet to be proven. Most

[22] Cf. Glinsmann & Dennis (1991).
[23] Cf. Moyal (1992), p. 465.

nutritionists, therefore, only recommend their use for specific cases of diabetics and obesity, duly accompanied by a strict control of caloric restrictions.

In opposition to these statements, the International Sweeteners Association, which congregates the main manufacturers and industrial users of synthetic sweeteners, has been disseminating quite different arguments on the same problems. Such has been the case, for instance, with the results of a survey conducted by B. Rolls and D. Shide, according to which

> "It seems logical that, when intense sweeteners replace sugar in foods, a reduction in energy intake will follow."
>
> "From an evaluation of the available data, ther is no consistent evidence that consumption of the sweetener increases food intake or body-weight. Indeed a number of studies indicate that consumption of the sweetener aspartame, either in familiar foods or drinks, may help to reduce caloric intake when compared to intake of their full-caloric sweetened counterparts (...). In fact, the wide body of evidence (...) suggests that consumption of these products is associated with better weight maintenance."[24]

The inexistence up to now, of conclusive data on the proclaimed nutritional efficiency of intense sweeteners may lead to a questioning of FDA's evaluation criteria. One of the criticisms to the agency's orientation in this regard relates to the permission awarded by it for the use of the label "diet" in products containing synthetic sweeteners, since this denomination may confound the consumers who expect to reduce or control their weight by substituting the caloric intake of their habitual meals.[25]

Another important addition to the 1938 FDCA was the Delaney Clause, or anticancer clause, which determined that a food additive should not be considered safe if its ingestion by persons or animals was able to produce cancer.[26] According to the FDA, additives in general - leaving aside pesticides and veterinary products - come within the following classification: (1) food additives; (2) substances generally recognised as safe (GRAS); (3) substances approved before the 1958 ammendments; and (4) colourants.

The term GRAS refers to a class of products like salt, vitamins and condiments. Its classificatory criteria were established in function both of widely adopted alimentary custom and of evidences accepted by the totality of the scientific community.[27] According to them, both saccharin and cyclamates were initially included in it, for having been previously approved by the FDA, and due to their wide diffusion on the market. Later on, however, complementary studies on the cancerous effects of these sweeteners have put in doubt their innocuity and their legal status *vis-à-vis* the Delaney clause.

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[24] Cf. Rolls & Shide (1993).
[25] Cf. FDA Consumer (1987).
[26] Cf. Taylor (1988).
[27] FDA Consumer, Oct. 1988.

Saccharin was historically the first intense sweetener to be synthesized. Its innocuity has been evaluated several times, through various toxicological studies undertaken by scientific committees in 1911, 1955 and 1974. Each one of them approved the commercialization of the product with recommendations on maximum daily dosages. According to a technical statement,

> "Saccharin is not metabolized and has no food value. This latter property caused it to be banned in the United States in 1912 because of the fear that people who used saccharin instead of sugar would be deprived of nutritional values (...). The primary users were diabetics : in some countries (e.g. France), saccharin was considered to be a drug, sold only in pharmacies and banned, even today, in processed foods..."[28]

At the end of the nineteenth century and beginnings of the twentieth, the consumption of saccharin was growing very rapidly in Europe, due to its competitive price in relation to sugar. In Germany it reached a level corresponding to 9 percent of sugar consumption. This performance unchained vigorous reactions from several governments of the Continent's main beet sugar production countries, which enacted legislations banning its free consumption by non-diabetics.[29] And, after two international conferences held in Paris in 1909 and 1913, eight European countries subscribed an International Convention for the Regulation of Saccharin. This agreement, oriented towards the prohibition of its use by food processing industries, and a greater control of its sales to the public, did not become effective due to the advent of World War I, during which all repressive laws against saccharin were lifted in most countries.[30]

These developments allow to observe that the European governments of that time were more interested in protecting their sugar industries, and the fiscal revenues which they provided, than in defending the health conditions of their populations. A similar statement can be made with regard to the United States, where the prohibition of saccharin was considered for the last time two decades ago, through a proposal made in 1977 by the FDA, on the basis of the results of a study undertaken by the Canadian Health Protection Branch, pointing to cancerous effects of the product on animals.

This happened at a time when saccharin was the only intense sweetener freely consumed in the United States, already then a country with a booming market for low-caloric foods and beverages, some of whose big corporations - like Coca Cola and PepsiCo - had invested millions of dollars in the manufacture and sales of their "diet products". These enterprises, through their National Soft Drink Association, petitioned the US Congress to prevent the banning of the product, while a Center of Sciences in the Public Interest, created by the main dealers of these beverages, claimed for a clarification of the toxicological tests

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[28] Cf. Mazur (1983), p. 449.
[29] Cf. Merki (1994), pp.196-198.
[30] *Idem*, p. 200.

of saccharin. Due to such pressures, the American legislators declared a moratorium on the prohibition of saccharin and determined the realization of further studies on the toxicity of this sweetener.

That moratorium has already been renewed six times, the last one until 2002, and according to the Calorie Control Council - an international association representing the interests of the low-calorie and reduced-fat food and beverage industries - saccharin has been approved both by the World Health Organization and by the European Union.

At least up to now, the same didn't occur yet with cyclamates, whose toxicological tests, effectuated in the United States during the 1960s, pointed to collateral cancerous effects of their ingestion by animals. This determinated their elimination from the category of GRAS products, and their reclassification, as pharmaceutical products for the treatment of diabetics and obesity, subject as such to preliminary legal authorization.[31] That prohibition, still effective in the United States, influenced the adoption of similar measures by the governments of other countries, like France and Britain.

Shortly later it, in 1974, the use of aspartame in foods and beverages was authorized for the first time by the FDA, a decision subsequently corroborated in 1981 and 1983. Despite this, its innocuity has never been fully accepted by all,[32] even taking into account the hundreds of studies and tests which have been made so far. Presently classified as a "general purpose sweetener", aspartame is enjoying the benefits of a free and rapidly expanding market in countries like the United States and Japan. But its use is still facing restrictions within the European Union, one of the largest producers and exporters of sugar in the world.

THE DYNAMICS OF COMPETITION WITH SUGAR AND STARCH SWEETENERS

Since the introduction of saccharin on the market, at the end of last century, the process of substitution of sugar by intense or synthetic sweeteners does not seem to have gone very far. In the 1980s, saccharin's share in world sweetener consumption was estimated at 4 percent. During the current decade, it has increased by one quarter, thus reaching an apparently stable level of 5 percent. The same stability - at the level of 2 percent - seems to be characterizing aspartame, nowadays the second most consumed synthetic sweetener on the world market. From what is shown by Diagram 1, we can perceive that starch sweeteners (glucose and isoglucose) are by far the main competitors of saccharose, whose markets they continue to erode, although at a decreasing pace. And this occurs above all due to their greater organic and technological closeness to sugar, coupled with a 20 to 30 percent price differential in their favour.

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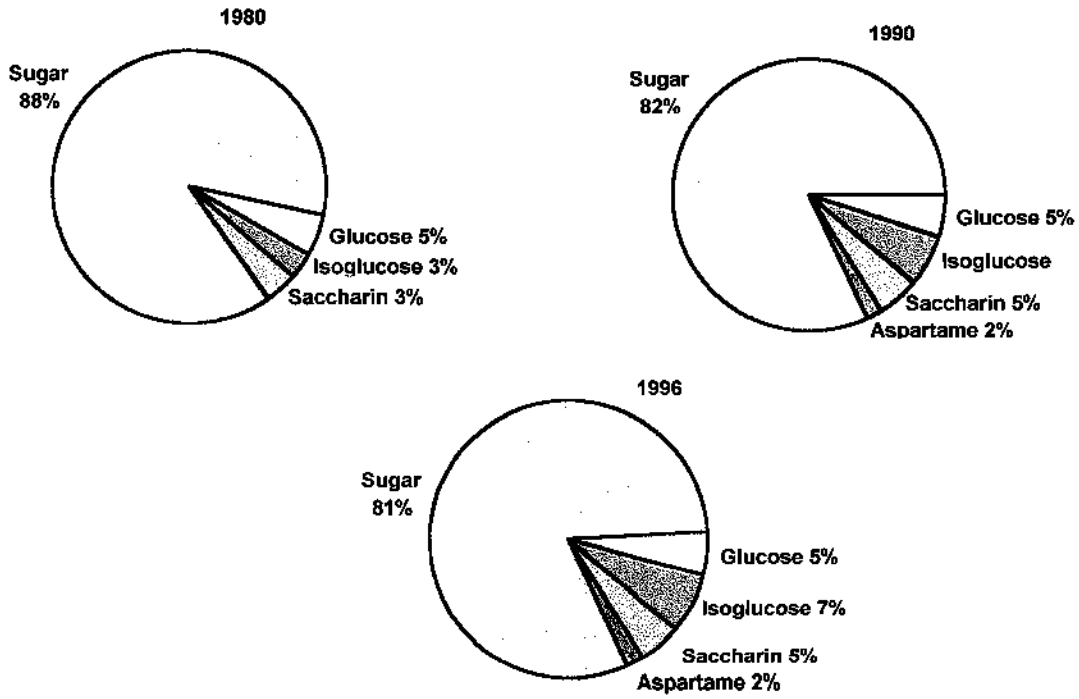
[31] Cf. Taylor (1988).
[32] See, for instance, the articles by Farber (1990)and Millstone (1994).

At the same time, however, we cannot fail to observe that the world consumption of synthetic sweeteners has increased 150 percent during these last twenty years alone, evolving from around 4.5 million tons in 1976 to almost 11 million in 1995. Until the mid-1970s, their main consuming areas were located in North America, particularly in the United States and Canada, whose overall consumption was then 20 percent above the Asian level. But, during the two subsequent decades, America's share decreased from 42 to 33 percent of world consumption, while that of Asia went up from 35 to 44 percent. According to Diagram 2, the participation rates of Europe on the one hand, and, of Africa and Oceania on the other remained stable at the levels of 21 and 1.5 percent respectively. In what follows, we shall discuss the main reasons and the main limits of the dynamics of substitution within observed market trends.

The use of alternative sweeteners tends to be determined by a combination of technical and economic factors. At the beginning, synthetic sweeteners seemed to emerge on the market merely as pharmaceutical products, indicated for the consumption of persons with diabetes. Such had been, for instance, the case of saccharin in the late 1880s.[33] Nonetheless its cheapness relative to sugar soon attracted the attention both of poorest people and of the industrial consumers of sweetening agents catering to them. This was the reason why its consumption in Germany increased almost 793 times between 1888 and 1900/01, from approximately 150 kilos to 118,9 tons.[34]

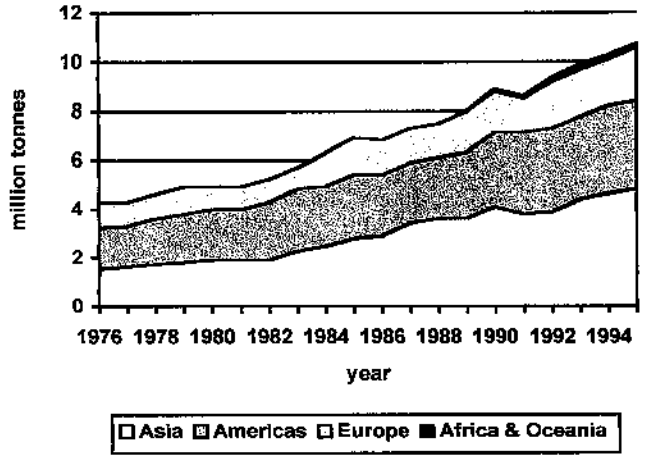
[33] According to the report by Merki (1993), pp.56/57.
[34] *Idem*, p. 60, table I.

Diagram 1
Market Share of the Main Sweeteners in the World



Source : F.I.R.S. (1997) La Campagne Sucrière 1995-1996, p. 71.

Diagram 2
The Consumption of Intense Sweeteners, by Region
(million tonnes, sugar equivalent)



Source : LMC (1997) p. 6.

To be sure, Constantin Fahlberg, the first manufacturer of this synthetic sweetener envisaged other (non-pharmaceutical) uses for it already in 1885, when he first presented his innovation at the international exhibitions of Antwerp and London, showing saccharin not only *in natura,* but also mixed with

starch sweeteners and incorporated to several foodstuffs and beverages.[35] Two years later, he even attempted to make an agreement with starch sweetener manufacturers for the joint sale of a "saccharin syrup" - a project that didn't succeed at that time, but which has become commonplace nowadays.[36] One of saccharin's first industrial consumers were the dark beer breweries of Northern Germany.[37] But, by the end of nineteenth century and the beginning of the twentieth, domestic consumption of sweeteners still prevailed over the industrial one, and, due to this, saccharin became at that time above all the "sugar of the poor people" both in the German and in the Austro-Hungarian empires.[38]

However, progress towards a larger substitution of sugar by saccharin came to a brusque halt in most of Continental Europe with the enactment from 1902 onwards (and in France even before that) of legislation that prohibited the sale of the latter to "healthy" and "normal" consumers. Until the advent of World War I, this legislation confined the legal sale of saccharin to pharmacies - a restriction which brought about a booming black market, increasingly supplied by firms of Switzerland, one of the few European countries in which its consumption and fabrication had remained free.[39] That situation was definitely changed only by the two World Wars, during which saccharin and other synthetic sweeteners - like Dulcin - became legally accepted substitutes of sugar, and were even promoted by governments as such.

For these reasons, later attempts to ban the use of saccharin in important markets like the USA were doomed to failure, besides being thwarted by the action of the beverage manufecturers' lobbies, as has been shown in the first part of this paper. Even so, its consumption decreased, or remained stable, in the Americas and Europe, while it sharply increased in Asia, whose share in its world consumption reached and surpassed the level of 50 percent during the 1980s (see Diagrams 3 and 4). The latter trend can be ascribed not only to the low prices of this sweetener, but also to other factors - such as different dietary patterns and lack of stricter foodstuffs legislation and fiscalization - whereas the opposite trend in Europe and in the Americas has been correlated with the upsurge of aspartame.

The consumption of cyclamates, after its ban in several countries, evolved in a similar way to that of saccharin, due to the increasingly usual blending of these two synthetic sweeteners. Within a world production of approximately 700 thousand tons (sugar equivalent) in 1995, Asian countries have become its main consuming centers with a joint share of 67 percent in world consumption. As shown on Diagram 5, the remaining 33 percent are concentrated mostly in Europe and in Latin America.

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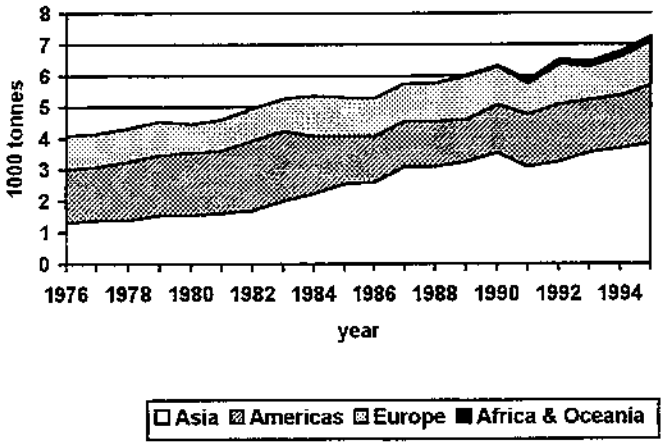
[35] *Idem*, pp. 54 and 61.
[36] *Idem*, pp. 61/62.
[37] *Idem*, p. 63.
[38] *Idem*, pp. 64-68.
[39] *Idem*, pp. 192 ff.

Diagram 3
The Consumption of Saccharin, by Region
(1000 tonnes, sugar equivalent)

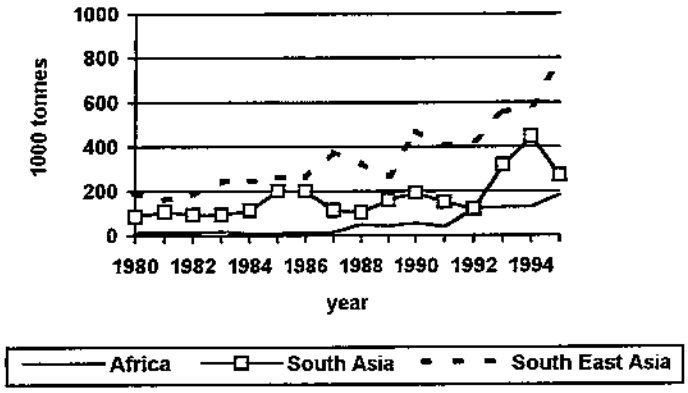


Source : LMC (1997) p. 7.

Annual growth rates of aspartame's world consumption have been six times bigger than those of saccharin and cyclamates (l8 and 3 percent respectively). The USA figure as the main consumer of this product from the very beginning of its appearance on the market, concentrating around two thirds of the world total. At least in that country, the growth of its consumption can be attributed, in part, to a substitution among synthetic sweeteners. Sales of aspartame began there in 1981 and, four years later, the levels of its *per capita* consumption had already reached the double of saccharin's. But it also reflected, as elsewhere, a phenomenal increase of the yearly growth rates in the consumption of synthetic sweeteners in general - which in the USA passed from 3.5 percent - during the 1970s to 10.4 percent in the following decade.

Europe represents the second market for aspartame, with a share of almost 19 percent in world consumption. The shares of Asia, Latin America, Africa and Oceania are much smaller. World production has been estimated around 2 million tons (sugar equivalent) in 1995. Its rapid expansion since the 1980s can be linked in part to an also rapid decline of saccharin consumption's growth rates.

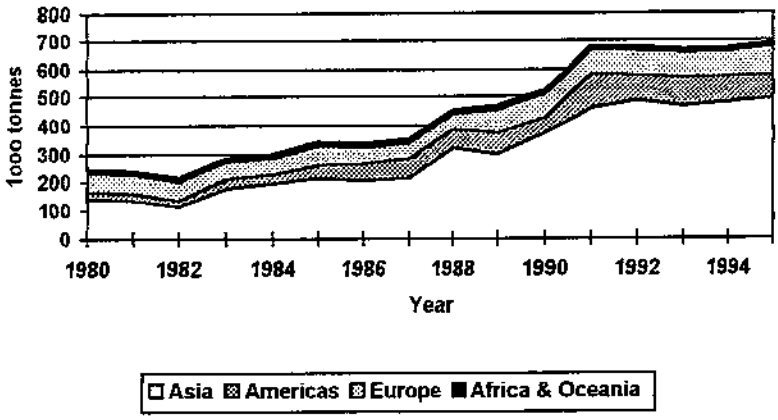
Diagram 4
Saccharin Sales in Leading Emerging Regions (1000 tonnes, sugar equivalent)



Source : LMC (1997) p. 8.

Even so there seems to be occurring nowadays in the world at large a redution in aspartame's rate of expansion, perhaps revealing a certain saturation of its main consumer markets. That expansion, contrarily to those of saccharin and cyclamates, has not been based on decreasing relative prices, but rather on the exaltation, by marketing and propaganda, of its superior organoleptic qualities *vis-à-vis* those of older sweeteners. It has also been associated to the diffusion of the trademark Nutrasweet adopted by aspartame's first manufacturers (Searle pharmaceutical laboratories, later on absorbed by Monsanto). During the first years of its existence, the product had even been protected by patents, allowing its manufacturers to obtain monopolistic profits.[40]

Diagram 5
The Consumption of Cyclamates, by Region (1000 tonnes, sugar equivalent)



Source : LMC (1997), p. 8.

[40] On this topic, see the article by Pelaez Alvarez (1996).

In fact, as can be seen from Table 3, at the beginning of its commercialization, the price of aspartame was much higher than those of its competitors. It was only with the approximation of the patent's expiration date that a more substantial decrease occurred. According to the data of Table 4, there even seem to exist two different markets for synthetic sweeteners : one consubstantiated by saccharin and cyclamates, whose prices are much inferior to those of sugar, and the other with products like aspartame, whose present price differentials with regard to sucrose are much smaller, and where, in consequence, competition occurs by the way of product differentiation.

That competition has been increasing in recent years through the introduction of new products like sucralose, alitame and acesulfame-K. The first one of these is an intense sweetener derived from sugar itself, thus leading to a reduction of carbohydrates intake, produced by a joint venture of Tate & Ly1e with Johnson & Johnson. The two others, like aspartame, originated both from pharmaceuticals, being produced respectively by Pfizer and by Hoechst. The latter has adopted a strategy of commercialization based on the synergism of blends of its product with aspartame. As we have already mentioned, acesulfame-K displays an aftertaste which reminds that of saccharin, but this charateristic almost disappears in the mixtures with aspartame, having the further advantage of doubling the sweetening power of the blend's both constituents.

Generally speaking, blends of sweeteners - both among intense sweeteners and of these with sugar and/or isoglucose - are becoming ever more popular. This is due not only to the greater taste flexibility that they provide to the foodstuffs and beverages in which they are incorporated, but also to essentially economic factors, such as the considerable cost reductions that their use ensures to industrial consumers of sweetening agents.[41]

Table 3
USA relative prices for high intensity sweeteners in 1985 (US$ per pound)

Sweeteners	Average Prices	Sweetening Power (sugar equivalent)	Relative Prices
Sugar	0,27	1	0,27
Isoglucose	0,20	1	0,20
Saccharin	2,90	300	0,01
Aspartame	90,00	180	0,54

Source : Nutrasweet Co. in McCann (1990), p. 79.

[41] See, for instance, Verdi & Hood (1993).

Table 4 Evolution of USA relative prices for selected high intensity sweeteners (US$ per pound)			
Years	Saccharin	Aspartame	Acesulfame-K
1989	0,01	0,36	0,20
1990	0,01	0,28	0,28
1991	0,01	0,28	0,28
1992	0,01	0,28	0,17
1993	0,01	0,17	0,17
1994	0,01	0,17	0,17
1995	0,01	0,17	0,17
1996	0,01	0,17	0,17

Source : Maxwell Consumer Report in USDA Sugar & Sweetener, Dec. 1996, p.79.

CONFLICTING VIEWS ON THE TRENDS OF SUBSTITUTION

Given all the data and features presented up to this point, a most important question still remains unanswered - namely, what will happen with the demand for sugar. In this field no agreement has been reached as yet, and we may for the moment only emphasize two conflictive and irreconciliable positions : one which argues that substitutionism is not taking place fast and directly; and the other according to which the structure of the market for sweeteners has already changed considerably, and will change even more as the current regulations are being removed. The former is represented, among others, by the British food economists Ben Fine *et alii* (1995), and the latter by the German agricultural economist Ulrich Sommer (1997) both of whom take the case of the European Union as their subject of analysis.

According to Fine and his associates, sugar on the one hand and synthetic sweeteners on the other configure completely different markets and different systems of production, subject as such to distinct regulatory policies. While sugar is defined by them as food, synthetic sweeteners are considered food additives. Examining the supply of the former within the European Union and the impact upon it of that of synthetic sweeteners, they conclude that "...while alternative low calorie sweeteners have probably restricted the growth in the use of sugar, the effect in practice has been to expand the total market for sweeteners." [42], and that this has occurred "without sugar being significantly displaced."[43]

Conversely, Sommer states in his abstract that:

> "...Overall, sugar sales have increased slightly, owing to greater use in the food industry. Household consumption, on the other hand, has clearly declined... *Per capita* sweetener consumption is currently growing at a rate of 4 percent per year. (...) Several

[42] *Op. cit.*, p. 32. According to the same authors, "the main threat ... to sugar producers is the vagaries of the world sugar system rather than substitutionism by sweeteners." (*Ibidem*)
[43] *Idem*, p. 145.

> institutions have in recent years demanded the abolition of production quotas in the sugar market (...). For the European Union as a whole, the abolition of production quotas would likely to provide in 2005/06 a decline in sugar sales by about 35%."[44]

It is true that his main concern refers to isoglucose and inulin syrup, whereas Fine *et alii* don't seem to worry at all with these products' performance. Despite of this, the respective conclusions of their works are sufficiently divergent from each other for making us think about whereto will the here described changes lead the markets in the future.

No doubts of this sort seem to exist elsewhere. According to a last February report of the International Sugar Organization, obtained from London via internet, "... in the United States, there is a growing evidence that intense sweeteners are competing directly with sugar (and HFCS) (and) analysts are beginning to change their view that aspartame was not having a negative impact on the sugar market." In other words, changes, far from being over, may now be just beginning...

[44] *Op. cit.*, p. 389.

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