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Probability and Banach Spaces

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INTRODUCTION

Probability, Banach spaces and their interplay have attracted the attention of the mathematical community since the early sixties. A number of mathematicians at the University of Zaragoza have been interested in this subject for some years and a Conference on Probability and Banach spaces, attended by probabilists and analysts from several countries, was held at this University in June 1985.

The main lecturers were E. Giné (Texas A&M), N.J. Kalton (Columbia-Missouri), G. Pisier (Paris VI) and J.L. Rubio de Francia (Madrid-Autónoma). Other invited speakers were F. Bombal (Madrid-Complutense), L. Drewnowski (Poznań), J. Esterle (Bordeaux), D.J.H. Garling (Cambridge), D. Nualart (Barcelona). Moreover three special sessions of contributed talks were held.

We would like to express our gratitude to all those who attended and helped to make the Conference such a success.

The Conference was sponsored by the following institutions: Universidad de Zaragoza (Rectorado, Decanato de la Facultad de Ciencias y C.U. de la Rioja), CAICYT, Consejería de Cultura de la Diputación General de Aragón, Diputación Provincial de Zaragoza, Caja de Ahorros de la Inmaculada, Caja de Ahorros de Zaragoza, Aragón y Rioja, to whom we wish to express our gratitude.

This volume constituted the Proceedings of the Conference with papers by L. Drewnowski, J. Esterle, D.J.H. Garling, E. Giné, N. Kalton, D. Nualart and J.L. Rubio de Francia. The contributions of F. Bombal and G. Pisier have been published elsewhere.

Finally we would like to thank Concha Abad and Nuria Martín for their secretarial services.

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ON THE DUNFORD AND PETTIS INTEGRALS

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1. Introduction.

We present here an operator theoretic approach to some recent results on Dunford and Pettis integration. Let (Ω, Σ, μ) be a finite positive measure space, X a Banach space, $f:\Omega \longrightarrow X$ a Dunford equiintegrable function, and $T = T_f : X^* \longrightarrow L_1(\mu);\ x^* \longmapsto x^*f$ the associated operator. Then T has the following two easily established properties (Proposition 5.1): (α) ker T is weak* countably compact, and (β) T maps convex weak* compact sets to weakly compact sets. Let $\mathcal{F}_X$ (resp., $\mathcal{C}_X$) be the family of all finite-dimensional (resp., Corson) subspaces of X. Define $K(f) = \bigcap\{T(B' \cap F^{\perp}) : F \in \mathcal{F}_X\}$ and $\check{X} = \bigcup\{\overline{L}'' : L \in \mathcal{C}_X\}$; here $F^{\perp}$ is the annihilator of F in X^*, $\overline{L}''$ is the weak* closure of L in X^{**}, and B' (resp., B''' below) is the closed unit ball in X^* (resp., X^{***}). Only the properties (α) and (β) are used in the proof of our main result, Theorem 5.4: K(f) is a weakly compact absolutely convex subset of $L_1(\mu)$ and $K(f) = T^{**}(B''' \cap X^{\perp\perp}) = T^{**}(B''' \cap \check{X}^{\perp\perp})$, where $^{\perp\perp}$ indicates annihilators taken in X^{***}; hence $\mathrm{dist}(T^*\psi, X) = \max\{|\int_\Omega \psi\varphi\, d\mu| : \varphi \in K(f)\}$ $= \mathrm{dist}(T^*\psi, \check{X})$ for every $\psi \in L_\infty(\mu)$. Some recent results of M. Talagrand are easy consequences of this theorem. For instance, if the range of the indefinite Dunford integral of f is contained in $\check{X}$, then f is Pettis integrable. If the weak* core of f over a set $E \in \Sigma$ is defined as $\mathrm{cor}''_f(E) = \bigcap\{\overline{\mathrm{co}}^{w^*} f(E - A) : A \in \Sigma, \mu(A) = 0\}$ and if we know that $\mathrm{cor}''_f(E)$ meets $\check{X}$ for every $E \in \Sigma$ with $\mu(E) > 0$, then f is Pettis integrable. Some properties of the sets K(f) for arbitrary weakly measurable functions f are also established.

2. Some notation and terminology.

Throughout, X is a fixed (but otherwise arbitrary) Banach space. The closed unit ball in its first three dual spaces X^*, X^{**} and X^{***} are denoted by B', B'' and B''', while the weak* closure operations in those dual spaces by $\overline{}'$, $\overline{}''$ and $\overline{}'''$, respectively. $\mathcal{F}_X$ is the family of all finite-dimensional subspaces of X.

As usual, every Banach space Z is identified with its canonical image in Z^{**} (so that $Z \subset Z^{**}$). If L is a subspace of Z (resp., Z^{**}) then $L^{\perp}$ (resp., $L^{\perp\perp}$) denotes its annihilator in Z^* (resp., Z^{***}).

A subset A of a topological space S is called

- countably closed if A contains the closure (in S) of each of its countable subsets;
- countably compact if each infinite subset (or sequence) in A has a cluster point in A.

(Ω, Σ, μ) is a finite positive measure space. $L_0(\mu)$, $L_1(\mu)$ and $L_\infty(\mu)$ denote the usual Lebesgue spaces of scalar measurable functions on (Ω, Σ, μ). $L_0(\mu)$ is an F-space under the topology of convergence in measure.

3. Corson spaces.

A Banach space Z has property (C) or, as we prefer to say, is a Corson space, if every family of closed convex subsets of Z with the countable intersection property has a nonempty intersection. This class of spaces, which we shall denote by $\mathcal{C}$, appeared already in Corson's 1961 paper [2], but had to wait until 1980 for a thorough investigation undertaken by R. Pol [11]. The following results about $\mathcal{C}$ are either explicitly stated in the work of Pol or easily deduced from it. The reader is referred also to [5] for a diagram (and the accompanying comments) showing the position of $\mathcal{C}$ among various other classes of Banach spaces.

Of crucial importance for us is Pol's dual characterization of (C) [11; §3.4], which we reformulate slightly.

(3.1) A Banach space Z is a Corson space iff every convex w^*-countably closed subset of Z^* is w^*-closed.

The next four results show that $\mathcal{C}$ has very good stability properties.

(3.2) $\mathcal{C}$ is closed under the formation of closed subspaces, quotients, finite products, and even arbitrary $c_0(\Gamma)$-products.

(3.3) $\mathcal{C}$ has the "three space property" If a Banach space Z has a closed subspace Y such that $Y \in \mathcal{C}$ and $Z/Y \in \mathcal{C}$, then $Z \in \mathcal{C}$.

(3.4) A Banach space Z is a Corson space if there exists a continuous linear operator with dense range from a Corson space into Z.

(3.5) The family $\mathcal{C}_X$ of all Corson (closed) subspaces of the Banach space X is countably upward directed by inclusion: For every sequence (L_n) in $\mathcal{C}$ there is an $L \in \mathcal{C}$ such that $L_n \subset L$ for all n.

Proof. For every n the subspace $M_n = L_1 + \dots + L_n$ is a continuous linear image of $L_1 \times \dots \times L_n$, which is in $\mathcal{C}$ by (3.2). Hence, by (3.4), $\overline{M}_n \in \mathcal{C}_X$. Finally, $L = \overline{\bigcup_n M_n} \in \mathcal{C}_X$ by [11; §3.2, Prop. 2], and $L_n \subset L$ for all n. (An argument using $(\sum_n L_n)_{c_0}$ is also possible.)

We define the Corson envelope of the Banach space X as

$$\check{X} = \bigcup_{L \in \mathcal{C}_X} \overline{L}'' ;$$

from (3.5) it follows that $\check{X}$ is a closed (even w*-countably closed) linear subspace of X^{**} containing X. The case when $\check{X} = X^{**}$ is very important for Pettis integration, see (5.5), but we do not know of any nontrivial conditions on X ensuring this equality.

From (3.2) and (3.3) we derive directly the following:

(3.6) If $M \in \mathcal{C}_X$ and $q_M : X \longrightarrow X/M$ is the quotient map, then

$$\mathcal{C}_{X/M} = \{ q_M(L) : M \subset L \in \mathcal{C}_X \}.$$

(3.7) Let $Z \in \mathcal{C}$ and let $S : Z \longrightarrow X$ be a continuous linear map. If H is a convex w*-countably closed and relatively w*-compact subset of X^*, then $S^*(H)$ is a convex w*-compact subset of Z^* and $S^*(H) = S^*(\overline{H}')$.

Proof. Since $Z \in \mathcal{C}$, we have only to check that $S^*(H)$ is w*-countably closed, and then apply (3.1). Let C be a countable subset of $S^*(H)$ and choose a countable set $A \subset H$ so that $C = S^*(A)$. Then $\overline{A}' \subset H$ and $\overline{A}'$ is w*-compact, hence $\overline{C}' \subset S^*(\overline{A}') \subset S^*(H)$.

As a corollary to (3.7), we note the following result:

(3.8) If H is a convex w*-countably closed and relatively w*-compact subset of X^*, then the following statements are equivalent:

(a) $H \cap F^{\perp} \neq \emptyset$ for all $F \in \mathcal{F}_X$.

(b) $0 \in \overline{H}'$.

(c) $H \cap L^{\perp} \neq \emptyset$ for all $L \in \mathcal{C}_X$.

Proof. Only (b)$\Longrightarrow$(c) has to be verified. Let $L \in \mathcal{C}_X$ and let $j : L \longrightarrow X$ be the identity embedding. Then $0 \in j^*(\overline{H}') = j^*(H)$ by (3.7). Hence there is an x^* in H such that $x^*|L = j^*(x^*) = 0$; thus $x^* \in H \cap L^{\perp}$ and so $H \cap L^{\perp} \neq \emptyset$.

4. Basic facts about the Dunford and Pettis integrals.

The reader is referred to [3] and [13] for more details and proofs; [9] and [4] are also recommended.

Let $f : \Omega \longrightarrow X$ be a weakly (or scalarly) measurable function, and consider its "conjugate" - the associated linear operator

$$T_f : X^* \longrightarrow L_0(\mu); \; x^* \longmapsto x^*f.$$