A NOTE ON MULTIPLICATION OF STRONG OPERATOR MEASURABLE FUNCTIONS

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(Communicated by Palle E. T. Jorgensen)

Abstract. Let \((\Omega, \Sigma, \mu)\) be a finite and positive measure space, and let \(U_1, \ldots, U_n\) be strongly measurable functions with values in the space of bounded linear operators on a Banach space. Then the product \(U_1 \cdots U_n\) is again strongly measurable.

In the paper The product of strong operator measurable functions is strong operator measurable, G. W. Johnson recently (see [Jo]) proved for a Hausdorff space \(K\) equipped with a finite Radon measure \(\mu\) and a separable Hilbert space \(H\) that the finite product \(U_1 \cdots U_n\) of strongly measurable operator-valued mappings \(U_i: K \to L(H)\) is again strongly measurable, where \(L(H)\) is the space of all linear bounded operators on \(H\). As mentioned there, the general result seems not to be known in the literature.

Here for a general Banach space \(X\) the above property will be established. First we give some notations and standard definitions. Let \((\Omega, \Sigma, \mu)\) be a finite and positive measure space. \(X, Y, X_1\) are Banach spaces, where \(S(X)\) is the unit sphere of \(X\) and \(L(X, Y)\) will denote the space of bounded linear operators \(T: X \to Y\).

Definition (see, e.g., [Jo]). (1) A function \(g: \Omega \to X\) is \(\mu\)-measurable if there exists a sequence \((g_n)\) of simple functions \(g_n: \Omega \to X\), such that

\[
\lim_{n \to \infty} \|g(\omega) - g_n(\omega)\| = 0 \quad \text{f.a.a. } \omega \in \Omega.
\]

(2) An operator-valued function \(U: \Omega \to L(X, Y)\) is strongly measurable if \(U(\cdot)(x): \Omega \to Y\) is \(\mu\)-measurable for all \(x \in X\).

Remark 1. Let \(X\) be separable, \((x_k) \subset S(X)\) be dense, \(Y\) be a Banach space, and \(U: \Omega \to L(X, Y)\) be strongly measurable. For \(\omega \in \Omega\) we have \(\|U(\omega)\| = \sup_{k \in \mathbb{N}} \|U(\omega)(x_k)\|\). Thus the function \(\omega \mapsto \|U(\omega)\|\) is measurable.

Lemma 1. Let \(f: \Omega \to X_1\) be \(\mu\)-measurable, let \(Y\) be a Banach space, and let \(U: \Omega \to L(X_1, Y)\) be strongly measurable operator-valued functions, such that \(\omega \mapsto \|U(\omega)\|\) is measurable. Then \(U \circ f: \Omega \to Y\) is \(\mu\)-measurable.

Received by the editors December 17, 1993 and, in revised form, February 15, 1994.
1991 Mathematics Subject Classification. Primary 46E10, 46G10.

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2815
Proof. Let \( \varepsilon > 0 \) be given. Since \( \omega \mapsto \|f(\omega)\| \) is measurable, there is an \( n \in \mathbb{N} \), such that for \( A_n := \{ \omega \in \Omega; \|f(\omega)\| \leq n \} \): \( \mu(\Omega \setminus A_n) < \frac{\varepsilon}{3} \). Similarly there is an \( m \in \mathbb{N} \), such that for \( D_m := \{ \omega \in A_n; \|U(\omega)\| \leq m \} \): \( \mu(A_n \setminus D_m) < \frac{\varepsilon}{3} \).

Since \( f(\cdot) \) is measurable, by the Egorov theorem (see [Din, p. 94]) there is a set \( \Omega_\varepsilon \subset D_m \), \( \mu(D_m \setminus \Omega_\varepsilon) < \frac{\varepsilon}{3} \), and a simple function \( g_\varepsilon: \Omega \to X_1 \), \( g_\varepsilon = \sum_{i=1}^l x_i \chi_{B_i} \), \( B_i \in \mathcal{G} \cap \Sigma \), such that

\[
\|f(\cdot)\chi_{\Omega_\varepsilon} - g_\varepsilon(\cdot)\|_\infty < \frac{\varepsilon}{m}.
\]

\( G(\cdot) := U(\cdot)g_\varepsilon(\cdot) \) is \( \mu \)-measurable, since \( G(\cdot) = \sum_{i=1}^l U(\cdot)(x_i) \chi_{B_i} \) and \( U \) is strongly measurable. Since \( \Omega_\varepsilon \subset D_m \), it follows that \( \|U(\omega)\| \leq m \) for \( \omega \in \Omega_\varepsilon \).

Thus, \( \|U(\cdot) \cdot f(\cdot)\chi_{\Omega_\varepsilon} - G(\cdot)\|_\infty < \varepsilon \).

Hence one obtains

\[
\forall \varepsilon > 0 \exists \Omega_\varepsilon \subset \Omega, \mu(\Omega \setminus \Omega_\varepsilon) < \varepsilon, \exists G: \Omega \to Y, \mu\text{-measurable, such that}
\[
\|U(\cdot) \cdot f(\cdot)\chi_{\Omega_\varepsilon} - G(\cdot)\|_\infty < \varepsilon.
\]

But this implies the measurability (see, e.g., [Din, p. 94, Theorem 1]).

**Theorem 1.** Let \( X \) be a Banach space. Then for \( U_i: \Omega \to L(X) \) strongly measurable \( (i = 1, \ldots, n) \) the product \( U_1 \cdots U_n \) is again strongly measurable.

**Proof.** It is obvious that by an induction argument one may restrict oneself to the case \( n = 2 \).

Hence let \( x \in S(X) \) be fixed. Since \( U_2(\cdot)(x) \) is \( \mu \)-measurable, there is a separable space \( X_0 \subset X \), such that \( U_2(\cdot)(x): \Omega \to X_0 \). Using the remark for \( \tilde{U}_1(\cdot) := U_1(\cdot)|_{X_0}: \Omega \to L(X_0, X) \), the map \( \omega \mapsto \|\tilde{U}_1(\omega)\| \) is measurable. Thus the lemma is applicable with \( X_1 := X_0, Y := X, f(\cdot) := U_2(\cdot)(x), \) and \( U := \tilde{U}_1 \), which shows that \( \tilde{U}_1(\cdot) \cdot U_2(\cdot)(x) = U_1(\cdot) \cdot U_2(\cdot)(x) \) is \( \mu \)-measurable.

**Remark 2.** In the paper *The composition of operator-valued measurable functions is measurable*, A. Badrikian, G. W. Johnson, and I. Yoo proved for separable Fréchet spaces \( E, F, G \) and \( G \) that for a measurable space \( (\Omega, \Sigma) \) and measurable maps \( T_1: \Omega \to L(E, F) \) and \( T_2: \Omega \to L(F, G) \), the product \( T_2 \circ T_1: \Omega \to L(E, G) \) is measurable again, where on \( L(E, F) \), resp. on \( L(F, G), L(E, G) \), the Borel-\( \sigma \)-algebra of the strong operator topology is considered. As a corollary [BJY, Corollary 3] they could deduce the main result of this paper for separable Banach spaces. Thus, their results overlap with the main result of this paper, neither one containing the other, and the proofs are different, too.

**References**


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