PROCEEDINGS OF THE
AMERICAN MATHEMATICAL SOCIETY
Volume 139, Number 8, August 2011, Pages 2657–2662
S 0002-9939(2011)10695-6
Article electronically published on January 11, 2011

SKEW CATEGORIES, SMASH PRODUCT CATEGORIES AND QUASI-KOSZUL CATEGORIES

DEKE ZHAO

(Communicated by Martin Lorenz)

Abstract. Let $\mathscr{A}$ be a small additive Krull-Schmidt locally radical finite category over a field K and let G be a finite group. We show that if $\mathscr{A}$ is a free G-category (resp. G-graded category), then $\mathscr{A}$ is quasi-Koszul if and only if the skew (resp. smash product) category $G * \mathscr{A}$ (resp. $\mathscr{A} \# G$) is.

1. Introduction

Koszul algebras were originally defined by Priddy in [9] and have arisen in many contexts: algebraic geometry, Lie theory, combinatorics, non-commutative geometry and topology. There exist numerous generalizing notations of Koszul algebras. For example, Berger [2] introduced the notation of N-Koszul algebras, and Cassidy and Shelton [3] introduced the notation of K_2 algebras. Very recently, Martínez-Villa and Solberg [7] introduced the notation of (weakly, quasi-)Koszul categories to obtain a naturally associated Koszul theory for any finite dimensional algebra.

Throughout this paper we will consider small additive categories $\mathscr{A}$ over a field K, free G-categories and G-graded categories where G is a finite group. For G-categories and G-graded categories, Cibils and Marcos [4] defined their skew categories and smash products categories, respectively, which provide a generalized category version of the Cohen-Montgomery Duality Theorem [5]. Inspired by the closeness of the (quasi-)Koszulity of algebras under the skew products and smash products [6, 10], we show that

Theorem. *Let $\mathscr{A}$ be a small additive Krull-Schmidt locally radical finite category over a field K and let G be a finite group.*

(i) *If $\mathscr{A}$ is a free G-category, then $\mathscr{A}$ is quasi-Koszul if and only if the skew category $G * \mathscr{A}$ is.*

(ii) *If $\mathscr{A}$ is G-graded, then $\mathscr{A}$ is quasi-Koszul if and only if $\mathscr{A}$ is.*

In Section 2 we recall the definitions of G-category, of skew category, and of G-graded category and give some basic facts. In Section 3 we recall the definitions of the syzygy of functor and of quasi-Koszul category and prove the Theorem.

Received by the editors November 22, 2009 and, in revised form, July 12, 2010.
2010 *Mathematics Subject Classification.* Primary 18A25, 18G10; Secondary 18B99.
Key words and phrases. Skew categories, smash product categories, quasi-Koszul categories, group-graded categories.

2. Skew categories and smash product categories

2.1. **Skew categories.** A *G-category* is a K-category $\mathscr{A}$ with firstly a set action of G on the set of objects $\mathscr{A}_0$ and secondly K-module maps $g : \mathrm{Hom}_{\mathscr{A}}(X,Y) \to \mathrm{Hom}_{\mathscr{A}}(gX,gY)$ for each $g \in G$ and $(X,Y) \in \mathscr{A}_0 \times \mathscr{A}_0$ satisfying $g(\varphi\psi) = (g\varphi)(g\psi)$ in case the morphism $\varphi\psi$ is composed in $\mathscr{A}$. Moreover for $g,h \in G$ and morphism ψ we have $(gh)\psi = g(h\psi)$ and $e\psi = \psi$ where e is the neutral element of G. In other words there is a group homomorphism from G to the group of autofunctors of $\mathscr{A}$. If the action of G is free on $\mathscr{A}_0$, we say that $\mathscr{A}$ is a free G-category.

Definition 1 ([4, Definition 2.3])**.** Let $\mathscr{A}$ be a G-category. The *skew category* $G * \mathscr{A}$ is a K-category with $(G*\mathscr{A})_0 = \mathscr{A}_0$ and morphisms $\mathrm{Hom}_{G*\mathscr{A}}(X,Y) = \bigoplus_{g\in G} \mathrm{Hom}_{\mathscr{A}}(gX,Y)$. Composition of morphisms is provided by the composition of $\mathscr{A}$ after adjustment.

An additive K-category $\mathscr{A}$ is said to be *Krull-Schmidt* if any object in $\mathscr{A}$ is a finite direct sum of objects with a local endomorphism algebra. Recall that the radical of a category $\mathscr{A}$, $\mathrm{rad}\mathscr{A}$, is a sub-bifunctor of $\mathrm{Hom}_{\mathscr{A}}(-,-)$ given by

$$\mathrm{rad}_{\mathscr{A}}(X,Y) = \{\psi \in \mathrm{Hom}_{\mathscr{A}}(X,Y) | \varphi\psi \in \mathrm{rad}(\mathrm{End}_{\mathscr{A}}(X)) \text{ for all } \varphi \in \mathrm{Hom}_{\mathscr{A}}(Y,X)\}.$$

Observe that we also have (see [8, Lemmas 4.1 and 4.2])

$$\mathrm{rad}_{\mathscr{A}}(X,Y) = \{\psi \in \mathrm{Hom}_{\mathscr{A}}(X,Y) | \psi\varphi \in \mathrm{rad}(\mathrm{End}_{\mathscr{A}}(Y)) \text{ for all } \varphi \in \mathrm{Hom}_{\mathscr{A}}(Y,X)\}.$$

We say that $\psi \in \mathrm{Hom}_{\mathscr{A}}(X,Y)$ is in $\mathrm{rad}^2_{\mathscr{A}}(X,Y)$ if ψ is a finite sum of the form $X \xrightarrow{\psi'_i} X'_i \xrightarrow{\psi''_i} Y$ with $\psi'_i \in \mathrm{rad}_{\mathscr{A}}(X,X'_i)$, $\psi''_i \in \mathrm{rad}_{\mathscr{A}}(X'_i,Y)$ for $i = 1,\cdots,m$ and $\psi = \sum_{i=1}^m \psi''_i\psi'_i$. Inductively define $\mathrm{rad}^n_{\mathscr{A}} := \mathrm{rad}_{\mathscr{A}} \cdot \mathrm{rad}^{n-1}_{\mathscr{A}}$. A K-category $\mathscr{A}$ is called *locally radical finite* if $\mathrm{rad}^i_{\mathscr{A}}(X,Y)/\mathrm{rad}^{i+1}_{\mathscr{A}}(X,Y)$ is finite dimensional over K for all $X,Y \in \mathscr{A}$ and $i \geq 0$.

Lemma. *If $X,Y \in \mathscr{A}$, then $\mathrm{rad}_{G*\mathscr{A}}(X,Y) \simeq KG \otimes_K \mathrm{rad}_{\mathscr{A}}(X,Y)$ and $\mathrm{rad}^n_{G*\mathscr{A}} \simeq \overbrace{KG \otimes_K \cdots \otimes_K KG}^{n} \otimes_K \mathrm{rad}^n_{\mathscr{A}}, n \geq 1$.*

Proof. Clearly $\mathrm{rad}_{\mathscr{A}}(gX,Y) \simeq \mathrm{rad}_{\mathscr{A}}(X,Y)$ for all $g \in G$. Assume that $\psi = \sum_{g\in G} \psi_g$ and $\varphi = \sum_{h\in G} \varphi_h$ where $\psi_g \in \mathrm{Hom}_{\mathscr{A}}(gX,Y)$ and $\varphi_h \in \mathrm{Hom}_{\mathscr{A}}(hY,X)$. Then $\varphi \cdot \psi \in \mathrm{rad}(\mathrm{End}_{G*\mathscr{A}}(X))$ if and only if $\varphi_h(h\psi_g) \in \mathrm{rad}(\mathrm{End}_{G*\mathscr{A}}(X))$ for all $g,h \in G$ if and only if $\psi_g \in \mathrm{rad}_{\mathscr{A}}(gX,Y)$ for all $g \in G$. Thus we obtain that

$$\begin{aligned}
\mathrm{rad}_{G*\mathscr{A}}(X,Y) &= \{\psi \in \mathrm{Hom}_{G*\mathscr{A}}(X,Y) | \varphi\psi \in \mathrm{rad}(\mathrm{End}_{G*\mathscr{A}}(X)) \\
&\qquad\qquad \text{for all } \varphi \in \mathrm{Hom}_{G*\mathscr{A}}(X,Y)\} \\
&= \{\psi = \sum_{g\in G} \psi_g, \psi_g \in \mathrm{Hom}_{\mathscr{A}}(gX,Y) | \sum_{g,h\in G} \varphi_h\psi_g \in \mathrm{rad}(\mathrm{End}_{G*\mathscr{A}}(X)) \\
&\qquad\qquad \text{for all } \varphi_h \in \mathrm{Hom}_{\mathscr{A}}(hY,X), h \in G\} \\
&= \{\psi = \sum_{g\in G} \psi_g, \psi_g \in \mathrm{Hom}_{\mathscr{A}}(gX,Y) | \varphi_h(h\psi_g) \in \mathrm{rad}(\mathrm{End}_{G*\mathscr{A}}(X)) \\
&\qquad\qquad \text{for all } \varphi_h \in \mathrm{Hom}_{\mathscr{A}}(hY,X), h \in G\} \\
&= \{\psi = \sum_{g\in G} \psi_g | \psi_g \in \mathrm{rad}_{\mathscr{A}}(gX,Y)\} \\
&\simeq KG \otimes_K \mathrm{rad}_{\mathscr{A}}(gX,Y) \\
&= KG \otimes_K \mathrm{rad}_{\mathscr{A}}(X,Y).
\end{aligned}$$

By induction, we have

$$\begin{aligned}\mathrm{rad}^n_{G*\mathscr{A}}(X,Y) &= \mathrm{rad}_{G*\mathscr{A}} \cdot \mathrm{rad}^{n-1}_{G*\mathscr{A}}(X,Y)\\ &\simeq \mathrm{rad}_{G*\mathscr{A}} \cdot (\overbrace{KG \otimes_K \cdots \otimes_K KG}^{n-1} \otimes_K \mathrm{rad}^{n-1}_{\mathscr{A}}(X,Y))\\ &\simeq \overbrace{KG \otimes_K \cdots \otimes_K KG}^{n} \otimes_K \mathrm{rad}^n_{\mathscr{A}}(X,Y).\end{aligned}$$

□

2.2. **Smash product categories.** A *G-graded category* $\mathscr{B}$ is a K-category together with a decomposition of morphisms $\mathrm{Hom}_{\mathscr{B}}(X,Y) = \bigoplus_{g\in G} \mathrm{Hom}_{\mathscr{B}}(X,Y)_g$ such that $\mathrm{Hom}_{\mathscr{B}}(Y,Z)_g \mathrm{Hom}_{\mathscr{B}}(X,Y)_h \subset \mathrm{Hom}_{\mathscr{B}}(X,Z)_{gh}$. In particular, $\mathrm{Hom}_{\mathscr{B}}(X,X)$ is a G-graded algebra for each $X \in \mathscr{B}$.

Definition 2 ([4, Definition 3.1])**.** Let $\mathscr{B}$ be a G-graded category. The *smash product category* $\mathscr{B}\#G$ is a category with $(\mathscr{B}\#G)_0 = \mathscr{B}_0 \times G$ and morphisms $\mathrm{Hom}_{\mathscr{B}\#G}((X,g),(Y,h)) = \mathrm{Hom}_{\mathscr{B}}(X,Y)_{h^{-1}g}$. Composition of morphisms is provided by the graded composition of $\mathscr{B}$.

Define a G-action on $\mathscr{B}\#G$ by $g(X,h) = (X,gh)$ and $gf = f \in \mathrm{Hom}_{\mathscr{B}\#G}((X,gh),(Y,gl))$ if $f \in \mathrm{Hom}_{\mathscr{B}\#G}((X,h),(Y,l))$. Then the category $\mathscr{B}\#G$ is a free G-category and the categories $G * (\mathscr{B}\#G)$ and $\mathscr{B}$ are equivalent [4, Corollary 3.3]. By the Lemma, we have the following:

Corollary. *If $X, Y \in \mathscr{B}$, then $KG \otimes_K \mathrm{rad}_{\mathscr{B}\#G}((X,g),(Y,h)) = \mathrm{rad}_{\mathscr{B}}(X,Y)$ for all $g, h \in G$.*

3. Quasi-Koszul categories

3.1. **Syzygy of functor.** Let $\mathscr{A}$ be an additive Krull-Schmidt locally radical finite K-category. We denote by $\mathrm{Mod}\mathscr{A}$ the category of contravariant additive functors from $\mathscr{A}$ to the category $\mathrm{Mod}K$ of K-vector spaces with natural transforms as morphisms.

A family of objects $\{\mathcal{F}(Y_i) | Y_i \in \mathscr{A}, i \in I\}$ is said to be *a family of generators for* $\mathcal{F} \in \mathrm{Mod}\mathscr{A}$ if for very $Y \in \mathscr{A}$,

$$\mathcal{F}(Y) = \sum_{i\in I} \mathcal{F}(\phi)(\mathcal{F}(Y_i))$$

where all but a finite number of $\phi_i : Y \to Y_i$ are zero, and $\mathcal{F} \in \mathrm{Mod}\mathscr{A}$ is *finitely generated* if it has a finite set of generator.

Denote by $\mathrm{mod}\mathscr{A}$ the full subcategory of $\mathrm{Mod}\mathscr{A}$ consisting of all finitely generated contravariant additive functors of $\mathrm{Mod}\mathscr{A}$. Then the category $\mathrm{mod}\mathscr{A}$ has, by [1, Corollary 4.13], minimal projective resolution. This gives rise to one-to-one correspondence between the indecomposable objects in $\mathscr{A}$ and the simple objects in $\mathrm{Mod}\mathscr{A}$, where an indecomposable object X in $\mathscr{A}$ gives rise to the simple object $S_X := \mathrm{Hom}_{\mathscr{A}}(-,X)/\mathrm{rad}_{\mathscr{A}}(-,X)$ in $\mathrm{Mod}\mathscr{A}$. Furthermore Yoneda's Lemma implies that an $\mathscr{A}$-module is projective in $\mathrm{mod}\mathscr{A}$ if and only if it is isomorphic to $\mathrm{Hom}_{\mathscr{A}}(-,X)$ for some $X \in \mathscr{A}$.

Definition 3. The *syzygy functor* $\Omega(\mathcal{F})$ of $\mathcal{F} \in \mathrm{Mod}\mathscr{A}$ is defined by the exact sequence

$$0 \to \Omega(\mathcal{F}) \to \mathrm{Hom}_{\mathscr{A}}(-,X) \to \mathcal{F} \to 0$$

for some $X \in \mathscr{A}$. Inductively, we can define the n-th syzygy functor $\Omega^n(\mathcal{F})$ of $\mathcal{F}$.

Remark. By Freyd's Theorem (see e.g. [8, p. 16, Theorem 3.1]) Mod$\mathscr{A}$ is an abelian category with coproduct and a faithful set of small projectives. Thus $\Omega(\mathcal{F}) : \mathscr{A} \to \mathrm{Mod}K, M \mapsto \Omega(\mathcal{F})(M)$ is a contravariant functor for any $\mathcal{F} \in \mathrm{mod}\mathscr{A}$.

3.2. **Quasi-Koszul categories.** Recall that an ideal in the category $\mathscr{A}$ is a subbifunctor of the Hom-functor. For two ideals $\mathcal{I}$ and $\mathcal{J}$ we define in a natural way inclusion, intersection and product. In particular the product of two ideals $\mathcal{I}$ and $\mathcal{J}$ is given by

$$\begin{aligned}\mathcal{I}\mathcal{J}(X,Z) = \Big\{\psi \in \mathrm{Hom}_{\mathscr{A}}(X,Z) | \psi \\ = \sum_{i=1}^{n} \varphi_i\phi_i, \phi_i \in \mathrm{Hom}_{\mathscr{A}}(X,Y_i), \varphi \in \mathrm{Hom}_{\mathscr{A}}(Y_i,Z), Y_i \in \mathscr{A}\Big\} \text{ for } X, Z \in \mathscr{A}.\end{aligned}$$

For an n-fold product of an ideal $\mathcal{I}$ with itself we write $\mathcal{I}^n$. Let $\mathcal{I}$ be an ideal in the category. For a contravariant functor $\mathcal{F} : \mathscr{A} \to \mathrm{Mod}K$ define $\mathcal{I}\mathcal{F} : \mathscr{A} \to \mathrm{Mod}K$ as the subfunctor of $\mathcal{F}$ given by

$$\mathcal{I}\mathcal{F}(M) = \sum_{X \in \mathscr{A}} \mathcal{F}(\mathcal{I}(M,X))$$

for all objects $M \in \mathscr{A}$. Clearly $\mathcal{I}\mathcal{F} \subseteq \mathcal{F}$ for any ideal $\mathcal{I}$ and any contravariant functor $\mathcal{F}$ in Mod$\mathscr{A}$

Definition 4 ([7, §5])**.** A contravariant functor $\mathcal{F}$ in Mod$\mathscr{A}$ is *quasi-Koszul* if it has a finitely generated projective resolution

$$\cdots \to \mathrm{Hom}_{\mathscr{A}}(-,X_i) \to \cdots \to \mathrm{Hom}_{\mathscr{A}}(-,X_0) \to \mathcal{F} \to 0$$

and $\mathrm{rad}_{\mathscr{A}}\Omega^i(\mathcal{F}) = \mathrm{rad}^2_{\mathscr{A}}(-,X_{i-1}) \cap \Omega^i(\mathcal{F})$ for all $i \geq 1$.

The category $\mathscr{A}$ is *quasi-Koszul* if every simple functor in Mod$\mathscr{A}$ is quasi-Koszul.

3.3. **Proof of Theorem.** Since the categories $G * (\mathscr{A}\#G)$ and $\mathscr{A}$ are equivalent, it is sufficient to prove (i). Assume that $\mathscr{A}$ is quasi-Koszul and $\mathcal{F}$ is a simple contravariant functor in Mod$\mathscr{A}$ having a finitely generated projective resolution

$$\cdots \to \mathrm{Hom}_{\mathscr{A}}(-,X_i) \to \cdots \to \mathrm{Hom}_{\mathscr{A}}(-,X_0) \to \mathcal{F} \to 0$$

and that $\mathrm{rad}_{\mathscr{A}}\Omega^i(\mathcal{F}) = \mathrm{rad}^2_{\mathscr{A}}(-,X_{i-1}) \cap \Omega^i(\mathcal{F})$ for all $i \geq 1$.

Suppose that $\mathcal{F} = \mathrm{Hom}_{\mathscr{A}}(-,X)/\mathrm{rad}_{\mathscr{A}}(-,X)$ for some indecomposable object $X \in \mathscr{A}$ and define

$$\mathcal{F}^* := \mathrm{Hom}_{G*\mathscr{A}}(-,X)/\mathrm{rad}_{G*\mathscr{A}}(-,X).$$

Then $\mathcal{F}^*$ is a simple contravariant functor in $\mathrm{Mod}\, G * \mathscr{A}$, and every simple functor in $\mathrm{Mod}\, G * \mathscr{A}$ is of this form, which has a finitely generated projective resolution

$$\cdots \to \mathrm{Hom}_{G*\mathscr{A}}(-,X_i) \to \cdots \to \mathrm{Hom}_{G*\mathscr{A}}(-,X_0) \to \mathcal{F}^* \to 0.$$

Thus it is enough to show that

$$(*) \quad \text{for all } i \geq 1,\ \mathrm{rad}_{\mathscr{A}}\Omega^i(\mathcal{F}) = \mathrm{rad}^2_{\mathscr{A}}(-,X_{i-1}) \cap \Omega^i(\mathcal{F}) \\ \text{if and only if } \mathrm{rad}_{G*\mathscr{A}}\Omega^i(\mathcal{F}^*) = \mathrm{rad}^2_{G*\mathscr{A}}(-,X_{i-1}) \cap \Omega^i(\mathcal{F}^*).$$

For any object $M \in \mathscr{A}$ and $i \geq 1$, we have

$$\begin{aligned}\mathrm{rad}_{G*\mathscr{A}}\Omega^i(\mathcal{F}^*)(M) &= \sum_{Y\in\mathscr{A}} \Omega^i(\mathcal{F}^*)(\mathrm{rad}_{G*\mathscr{A}}(M,Y)) \\ &= \sum_{Y\in\mathscr{A}} \Omega^i(\mathcal{F}^*)(KG\otimes_K \mathrm{rad}_{\mathscr{A}}(M,Y)) \\ &= \sum_{Y\in\mathscr{A}} KG\otimes_K KG\otimes_K \Omega^i(\mathcal{F})(\mathrm{rad}_{\mathscr{A}}(M,Y)) \\ &= KG\otimes_K KG\otimes_K \mathrm{rad}_{\mathscr{A}}\Omega^i(\mathcal{F})(M);\end{aligned}$$

that is, for all $i \geq 1$,

$$\text{(I)} \qquad \mathrm{rad}_{G*\mathscr{A}}\Omega^i(\mathcal{F}^*) = KG\otimes_K KG\otimes_K \mathrm{rad}_{\mathscr{A}}\Omega^i(\mathcal{F}).$$

By the Lemma, we have

$$\mathrm{rad}^2_{G*\mathscr{A}}(-,X_{i-1})\cap\Omega^i(\mathcal{F}^*) = KG\otimes_K KG\otimes_K \mathrm{rad}^2_{\mathscr{A}}(-,X_{i-1})\cap\Omega^i(\mathcal{F}^*) \quad \text{for all } i\geq 1.$$

Since $\Omega^i(\mathcal{F}^*) \subseteq \mathrm{rad}_{G*\mathscr{A}}\mathrm{Hom}_{G*\mathscr{A}}(-,X_{i-1})$ for all $i \geq 1$,

$$\begin{aligned}\Omega^i(\mathcal{F}^*)(M) &\subseteq \mathrm{rad}_{G*\mathscr{A}}\mathrm{Hom}_{G*\mathscr{A}}(-,X_{i-1}) \\ &= \sum_{Y\in\mathscr{A}} \mathrm{Hom}_{G*\mathscr{A}}(-,X_{i-1})\mathrm{rad}_{G*\mathscr{A}}(M,Y) \\ &= KG\otimes_K KG\otimes_K \mathrm{Hom}_{\mathscr{A}}(-,X_{i-1})\mathrm{rad}_{\mathscr{A}}(M,Y) \\ &= KG\otimes_K KG\otimes_K \mathrm{rad}_{\mathscr{A}}\mathrm{Hom}_{\mathscr{A}}(-,X_{i-1})(M).\end{aligned}$$

On the other hand, note that $\Omega^i(\mathcal{F}) \subseteq \mathrm{rad}_{\mathscr{A}}\mathrm{Hom}_{\mathscr{A}}(-,X_{i-1})$. This yields that $\Omega^i(\mathcal{F}^*) = KG\otimes_K KG\otimes_K \Omega^i(\mathcal{F})$. Hence

$$\text{(II)} \qquad \mathrm{rad}^2_{G*\mathscr{A}}(-,X_{i-1})\cap\Omega^i(\mathcal{F}^*) = KG\otimes_K KG\otimes_K \mathrm{rad}^2_{\mathscr{A}}(-,X_{i-1})\cap\Omega^i(\mathcal{F}).$$

Now $(*)$ follows by combining (I) and (II). This completes the proof. □

References

1. M. Auslander, *Representation theory of Artin algebras. I*, Comm. Algebra **1**(1974), 177–268. MR0349747 (50:2240)
2. R. Berger, *Koszulity for nonquadratic algebras*, J. Algebra **239**(2001), 705–734. MR1832913 (2002d:16034)
3. T. Cassidy and B. Shelton, *Generalizing the notion of Koszul algebra*, Math. Z. **260**(2008), 93–114. MR2413345 (2009e:16047)
4. C. Cibils and E.N. Marcos, *Skew category, Galois covering and smash product of a k-category*, Proc. Amer. Math. Soc. **134**(2006), 39–50. MR2170541 (2006e:18003)
5. M. Cohen and S. Montgomery, *Group-graded rings, smash products, and group actions*, Trans. Amer. Math. Soc. **282**(1984), 237–258. MR728711 (85i:16002)
6. R. Martínez-Villa, *Skew group algebras and their Yoneda algebras*, Math. J. Okayama Univ. **43**(2001), 1–16. MR1913868 (2003g:18013)
7. R. Martínez-Villa and Ø. Solberg, *Graded and Koszul categories*, Appl. Categor. Struct. **18**(2010), 615–652.
8. B. Mitchel, *Rings with several objects*, Adv. Math. **8**(1972), 1–161. MR0294454 (45:3524)

9. S.B. Priddy, *Koszul resolutions*, Trans. Amer. Math. Soc. **152**(1970), 39–60. MR0265437 (42:346)
10. D.K. Zhao and Y. Han, *Koszul algebras and finite Galois coverings*, Sci. China Ser. A **52**(2009), 2145–2153. MR2550272

Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing 100190, People's Republic of China

E-mail address: deke@amss.ac.cn

Current address: School of Applied Mathematics, Beijing Normal University at Zhuhai, Zhuhai, 519087, People's Republic of China