Ecological Economics 142 (2017) 268–281

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Methodological and Ideological Options

An Agent-based Model of the South African Offshore Hake Trawl Industry: Part I Model Description and Validation

Rachel Cooper *, Astrid Jarre

Marine Research Institute and Department of Biological Sciences, University of Cape Town, Private Bag X3, Rondebosch 7701, Cape Town, South Africa

ARTICLE INFO

Article history:
Received 27 July 2016
Received in revised form 18 June 2017
Accepted 23 June 2017
Available online 10 July 2017

Keywords:
Agent-based modeling
Ecological-economic models
Hake
South Africa
Fishing industry
Fishery management

ABSTRACT

The most valuable component in South Africa's fishing industry is its hake fishery, which targets two species, the shallow-water (*Merluccius capensis*) and deep-water (*M. paradoxus*) Cape hakes. Modelling provides a means to assist in understanding the dynamics of the economic system of this fishery and identify potential links to the ecological system in future, which can inform management. This study develops and describes a novel agent-based model of the South African offshore hake trawl industry, *HakeSim*, which captures drivers such as fuel price, catch per unit effort, export markets, exchange rate, industrial organization and uncertainty in catches as a proxy for environmental uncertainty. It allows identification of key drivers and their relative importance to the industry to be assessed. It has desirable and realistic sensitivities and it can successfully reproduce profitability scenarios for the industry under different fuel prices. Fuel prices above ZAR18.783 per litre, which could result from increased prices or reduced subsidies, are demonstrated to push the modelled fishing companies to making losses, which could potentially reduce employment. This model represents a strategic tool for management and significant advancements over existing bio-economic and agent-based models of fisheries.

1. Introduction

The most valuable component in South Africa's fishing industry is its hake fishery, which targets two species, the shallow-water (*Merluccius capensis*) and deep-water (*M. paradoxus*) Cape hakes. It accounts >50% of overall fisheries value in the country (Butterworth and Rademeyer, 2005; Powers et al., 2010), with landed catch worth approximately ZAR (South African Rand) 2.5 billion in 2008 (Petersen et al., 2010), and is presently estimated at ±ZAR 5 billion (Durholtz, 2014, personal communication). It also generates approximately 30,000 jobs (Rademeyer et al., 2008a), and is estimated to comprise as much as half of all fish eaten in the country (Bacela et al., 2003). The largest sector of the hake fishery is offshore demersal trawling, which lands 85% of the catch (Field et al., 2013), and is an important contributor to the large post-1990 export market for South African hake (Crosoer et al., 2006).

It is known that when fisheries are managed for long-term sustainability and only the ecological context is considered, while human aspects are ignored, failure of management often results. Therefore, the international literature generally acknowledges that fisheries need to be managed with economic and social objectives in addition to ecological ones (Browman and Stergiou, 2005; Folke et al., 2007; Garcia and Charles, 2008; Pitcher and Lam, 2010). A better understanding of the economic structure and function of the hake industry and its interaction and connection to the ecological system, will serve to inform management. Successful actions related to sustainability are underpinned through the linkages of ecosystems to social and economic systems (Folke et al., 2007). Furthermore, a current scientific challenge is to find coherence among the economic, social, ecological and institutional sectors of fisheries through the utilization of all pertinent knowledge (Garcia and Charles, 2008). As a step towards this, modelling provides a means to assist in understanding the dynamics of the economic system and identify potential links to the ecological system. Modelling is an approach that can be used to test understanding, synthesize knowledge and make predictions. Blackford et al. (2010), and Starfield and Jarre (2011) suggest that it is a useful means of conducting interdisciplinary research.

In the hake industry, several economic factors are known to have importance for the hake fishing industry. Exchange rate and market value of fish affect the ZAR price of hake, fuel price and catch per unit effort reflect the cost to companies to catch hake, and industrial organization affects company operations (see for example BCLME, 2004, 2006). Many of these factors, such as fuel price (Sumaila et al., 2008) and exchange rate (Asche, 2014) are known to be important internationally for fisheries profitability. The interaction of these and other variables affect company behaviour, and profits. To understand the function of the South African offshore hake trawl industry, it is therefore valuable to produce a novel prototype model to examine the effect on and relative importance of these and other factors for the industry. The aim of this study is to develop and describe an agent-based model that captures a variety of these

* Corresponding author.
E-mail addresses: Rachel.Cooper@protonmail.com (R. Cooper), astrid.jarre@uct.ac.za (A. Jarre).

http://dx.doi.org/10.1016/j.ecolecon.2017.06.026
0921-8009/

important drivers for the industry (Fig. 1). This model is designed within the framework of ultimately linking it to an ecosystem model of the Southern Benguela.

There is much complexity involved in the industrial structure of companies and company clusters in the offshore hake industry, as well as variability in the types of product that they sell and their fleet compositions (Cooper et al., 2014). Given this complexity and the heterogeneity of fishing vessels, companies and markets involved in the industry, agent-based modelling is particularly well suited for modelling it. Agent-based models (ABMs) capture complex systems comprised of heterogeneous, autonomous entities, 'agents', that interact with each other and their modelled environment through behaviours governed by simple rules, and which give rise to the behaviour of the system as a whole (Macal and North, 2010). ABMs allow the capturing of individual-level information, complexity, interdisciplinary and cross-scale perspectives, giving greater predictive and explanatory power (An et al., 2005), particularly in the broader ecological-economic context within which the present model is developed. Computational models like ABMs have the advantages of being able to deal with complex, stochastic systems, and of being able to model how the activities of elements at one scale have impacts on patterns observed at another scale (Levin et al., 1997). They allow the modelling of heterogeneous economic agents and therefore represent a new and alternate way of modelling and understanding economic systems (Deissenberg et al., 2008). This may be especially advantageous in modelling the economics of resource-extraction systems, such as fisheries, where not only are the economic agents heterogeneous but where

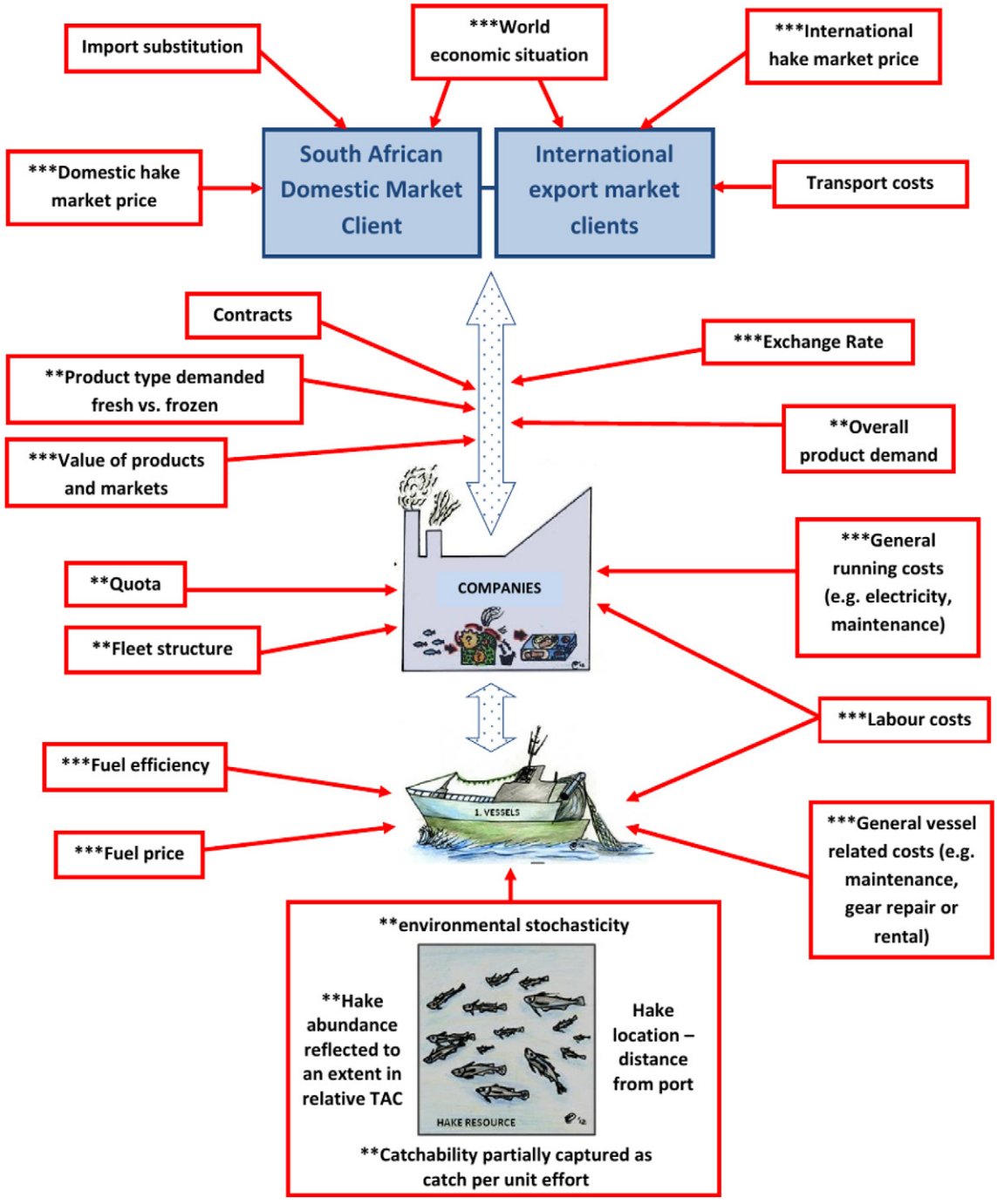

Fig. 1. A variety of external parameters known to affect the South African offshore demersal hake trawl fishing industry. Parameters that are captured in HakeSim are marked ***. Illustrations by R. Cooper.