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Hedonic evaluation of coral reef fish prices on a direct sale market

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ABSTRACT

Using two-stage Rosen's model, this evaluation aims to deduce the implicit prices of the coral-reef fish species most commonly encountered in road-side market in Moorea (French Polynesia) during 2014–2015, from the prices of bundles of species, called tuis. Index value are calculated which vary, all else equal, between 33% (*Selar*) and 137% (*Acanthurus*) of the price of the reference species (*Scarus*). Estimating translogarithmic specifications allow the identification of positive cross-species elasticities which imply complementarity between reef species in each tui. The composition of tuis is therefore a market strategy to enhance the value of catches. These results demonstrate the relevance of empirical economic analysis in improving the understanding of small-scale coral-reef fisheries in the Pacific.

1. Introduction

World-wide, coral reefs support small-scale subsistence fisheries [7,15]. These are particularly important in the South Pacific, where coastal communities are strongly dependent on reef fisheries [24,34]. The subsistence nature of these fisheries has often led to the assumption that, with the exception of export-oriented fisheries, their dynamics and the associated trade in fish products cannot be fully explained by standard market behaviour [26]. Indeed, the existing social science research on coral reef fin-fish fisheries in the Pacific is largely focused on their ethnographical and sociological characteristics and non-market determinants of their evolution [2,8,17,23].

The aim of this article is to examine the extent to which economic analysis can help explain the patterns of fish sales and fish prices in a Polynesian coral reef fin-fish fishery in the South Pacific. We assess the extent to which different taxa of reef fish attract different prices, reflecting relative supply and demand characteristics. In order to highlight such pricing strategies, we use data from a survey of fish sales on the island of Moorea, French Polynesia. Fishing plays an important role on Moorea, as a source of food for the local population, of income for fishers, and as an important aspect of Polynesian cultural identity [29,34,40]. The majority (58%) of the fish landed are taken from the lagoon [42], and a fraction of these are sold in lots called tuis. Each tui is composed of individuals of one or several different species of fish, tied together in strings of varying length. This local market is composed of multiple outlets along the island's coastal road, where fishers present their landings (tuis hanging from a rack) and consumers come to buy fresh fish [25,31,34]. Both fish buyers and sellers are sensitive to the quality of the fish offered for sale. They also have a good knowledge of the value of each species, and of the value of tuis composed of different

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species as well as the distribution of prices across outlets. Therefore, the willingness of buyers to pay for an additional quantity or quality of a species of fish is likely to be equivalent to the costs that a fisher would incur to provide it, which should also equal the value that they expect to derive from the market.

To identify fish pricing strategies, we apply a hedonic modelling approach which accounts for different sources of price heterogeneity. With the required precautions, using the principle of revealed preferences [36], this method enables estimation of the implicit price of a non-marginal variation in the length (taken as a measure of the quantity) of individual groups of fish species, based on the price of the tui composed of these species groups. Indeed, fish buyers pay a price based on their knowledge of the species groups that compose the tui: their preference for each species group is thus expressed as a monetary amount equivalent to their willingness to pay to acquire an additional quantity of this species group.

Our analysis demonstrates how applied economic methods can be used to elicit the relative economic value of different species of reef fish landed in a small-scale fishery. Estimates of the market value of species groups frequently observed in tuis in Moorea reveal that implicit prices of fish may vary by a factor of four to five across species groups. These prices are affected by the origin of the catch and fishing techniques used. The results, derived from the fraction of catch that is sold, may be used as a guide to assessing the economic stakes associated with changes in the composition of catches in the broader, subsistence-oriented and non-market components of the fishery. The results may also help inform the design of management strategies for the fishery, taking into account economic drivers of fishing pressure on this local market. Beyond the fishery under study, the results also highlight the relevance of empirical economic analysis to improve the understanding of small-scale coral-reef fisheries in the Pacific, and demonstrate a methodology to investigate the economic stakes associated with changes in the structure of their production, which could be applied across a broad range of contexts.

2. Context and data: tui sales on the Island of Moorea, French Polynesia

Coral reef fishing is a key activity for the coastal communities of French Polynesia. On the island of Moorea, fishing is strongly embedded in the livelihood and lifestyle of the local population, with most households engaged in a fishery-related activity [24,34,38,43]. A fraction of the landings of Moorea's small-scale fishery is sold along the roadside, generally close to the fisher's home in the form of strings of fish called tuis. The prices of individual tuis are observed through direct surveying of the sellers. Tui composition varies significantly, being made up of the same species or a mix of species, and of variable numbers of fishes of different sizes.

Tui prices and composition were surveyed on Moorea during 2014 and 2015 along the 60 km ring road. The survey documented the price of tuis sold. The species composition and sizes of fish on each tui were determined from photographs taken of each seller's rack at the time of the survey, with fish lengths calculated based on comparison with a scale bar of known size (see Rassweiler et al. [34]). Over the two years, 12,002 individual fishes were measured, of which there were 8 568 records with complete information, incorporated in 742 tuis sold by 164 sellers[6] and the majority of these (79.88%) are the fishers themselves. The mean number of tuis observed[7] per seller on a given day was 4–5, with a maximum of 23, and half of the sellers were selling 3 tuis or more. Fish on each tui were identified taxonomically from the photographs with variable levels of precision (usually to genus or species). The identified taxa were aggregated into 37 functional groups (here called species groups). Parrotfish that had been noted as potentially belonging to two or more taxa (*e.g.*, *Scarus/Chlorurus*) were assumed to belong to the first group listed. A range of non-reef taxa were aggregated within a group designated "pelagic" (*Cheilopogon, Coryphaena, Cypselurus, Katsuwonus, Sarda, Scombridae, Thunnus*). A large number of the observed tuis were composed of single-species groups: 360 out of 742. Multi-species group tuis were composed on average of 3 different species groups, and rarely contained more than 7.

The resulting database contains three dimensions: the tui t of seller i composed of several species groups j. Table 1 provides summary statistics on the composition of the observed tuis. The data reveal that some species groups are commonly encountered in a majority of the recorded tuis with consistent lengths offered across multiple sellers. Indeed, the total length of fish offered with the first fourteen species groups (in grey) in Table 1 represents the vast majority (95.85%, 4th column) of the total length of available fish across all the recorded tuis. Other species groups are more rarely encountered, and they appear in a limited number of tuis presented by some sellers. Within the same tui, the number and size of the fish pieces are negatively correlated (Rearson's r = −0.373) and the species groups most frequently encountered consist of smaller fish. The median length is about 22 cm for the four most frequent species groups and 26 cm for the others.

According to these observations, the prices of the 742 tuis vary by 482 CFP[8] (standard-deviation) around an average of 1773 CFP and their lengths by 106[3a] cm around an average length of 249[3b] cm. These tuis are characterized by substantial heterogeneity along several dimensions, particularly with respect to their species-group composition. Almost half of the sample (361 tuis out of 742) is composed of single-species groups, corresponding to 42% of the total length of fish sold on this market by three quarters of the sellers (118 out of 164). These single-species tuis are composed of 21 of the 37 species groups recorded in roadside sales. The survey of 742 tuis includes both species groups characterized by smaller- (*Acanthurus*, *Siganus* and *Myripristis*) and larger-bodied (*Epinephelus and Naso*) fish, between 16 and 39 cm each. The prices of these tuis vary across species groups and sellers from 850 CFP to 2000 CFP, around an average price of 1620 CFP (standard deviation, SD = 594 CFP). The lengths of all fish offered on individual tuis also vary greatly with a 107 cm standard deviation around an average length of 216 cm. It should be noted that price and length variations are positively correlated, but these correlations are weak between tuis (Pearson's r = 0.2737) as well as between species groups[9] (Pearson's r = 0.1375). Therefore, price variations among tuis and among species groups are not a simple function of the number or total length of fish on each tui.

In the sample, more than 90% of tuis containing *Selar* or Pelagic taxa are single-species tuis, meaning that these species are rarely mixed. By contrast, the proportion of tuis containing only *Parupeneus*, *Epinephelus*, *Chlorurus* or *Mulloidichthys* does not exceed 6%, indicating that these species groups are frequently mixed with others.

The large number of single-species tuis and their broad taxonomic representation allowed calculation of average prices of a number of individual species groups. Table 2 provides statistics regarding the characteristics of these tuis, including average and standard deviation of prices per species group for the 11 species groups observed in the survey among the 14 most frequent.

Tables 1 and 2 highlight the strong heterogeneity of tuis in terms of length, price and species group composition. Using a benchmark length of 10 cm to calculate species-group prices, we observe that the price of the 11 most frequent species groups varies considerably: the species

[6] 559 tuis sold by 123 fishers in 2014, and 183 tuis sold by 41 fishers in 2015.

[7] This was the number observed at the moment of sampling, so in certain cases, may be an underestimate of the total number of tuis offered for sale by a seller each day, as some tuis may already have been sold.

[8] The local currency is the Pacific Franc, Compagnie Française du Franc: 1 CFP = 0.008380 Euro as of March 2021.

[9] Correlation is calculated with the length and the price of the 118 single-species groups (Table 2).

Table 1
Characteristics of the tuis observed in the survey.

Species group j (by decreasing number of tuis)	Num. of. sellers	Num. of tuis	% of tuis in sample containing each species group	Num. of other species groups present in tuis sold by seller	Total Length of each species group (cm)	% of Total Length in sample	Average Length of species group j in single tuis (cm)	SD Length of species group j in single tuis (cm)	Average Price of a tui (CFP)	SD Price of a tui (CFP)	Average Length of fish of species group j (cm)	SD Length of fish of species group j (cm)	CIG (Index of ciguatera risk absence)
Scarus	114[a]	311[b]	42%[e]	27[j]	57,734	31.2%	186	109	1926	246	23	5	100
Chlorurus	78[c]	140[d]	19%[f]	21	9813	5.30%	70	66	1900	301	24	6	100
Parupeneus	81	130	18%	25	11,121	6.01%	86	67	1919	247	23	4	100
Myripristis	59	115	15%	28	18,924	10.2%	165	117	1939	249	19	3	100
Mulloidichthys	75	108	15%	27	11,737	6.34%	109	88	1898	296	22	4	100
Siganus	55	104	14%	24	15,609	8.43%	150	104	1952	215	19	3	100
Pelagic	20	90	12%	4	15,739	8.51%	175	76	864	549	30	13	100
Naso	49	85	11%	21	6760	3.65%	80	71	1929	269	28	13	100
Epinephelus	53	73	10%	22	8698	4.70%	119	136	1986	117	22	5	75
Acanthurus	43	58	8%	21	6427	3.47%	111	108	1922	226	19	4	100
Cephalopholis	46	55	7%	21	2567	1.39%	47	29	2000	0	21	5	67
Sargocentron	37	52	7%	24	2355	1.27%	45	31	1885	307	20	3	100
Lutjanus	24	30	4%	20	1968	1.06%	66	68	1967	183	22	5	40
Selar	7	30	4%	2	7798	4.21%	260	91	1350	494	20	4	100
Monotaxis	14	17	2.29%	17	675	0.36%	40	23	2000	0	26	9	40
Cheilinus	13	16	2.16%	15	730	0.39%	46	25	1906	272	24	6	75
NI (Non Identified)	10	16	2.16%	16	604	0.33%	38	21	1813	512	25	6	40
Kyphosus	6	15	2.02%	13	830	0.45%	55	35	2000	0	30	7	100
Lethrinus	13	15	2.02%	12	566	0.31%	38	23	1933	258	27	12	40
Calotomus	14	14	1.89%	12	603	0.33%	43	28	1893	289	25	4	100
Gnathodentex	10	11	1.48%	15	542	0.29%	49	24	1955	151	22	3	100
Carangoides	6	7	0.94%	9	383	0.21%	55	29	1857	244	41	23	100
Epibulus	7	7	0.94%	11	228	0.12%	33	9	2000	0	26	8	100
Tylosurus	4	7	0.94%	3	478	0.26%	68	35	714	567	67	36	100
Caranx	4	6	0.81%	5	333	0.18%	55	33	2000	0	33	17	40
Crenimugil	4	6	0.81%	12	333	0.18%	55	44	2000	0	22	2	40
Albula	2	4	0.54%	1	288	0.16%	72	14	1750	289	65	19	100
Ctenochaetus	3	3	0.40%	8	94	0.05%	31	26	1833	289	18	3	75
Pseudobalistes	3	3	0.40%	0	188	0.10%	63	10	2000	0	63	10	100
Sphyraena	3	3	0.40%	6	275	0.15%	92	76	1833	289	44	21	100
Chanos	2	2	0.27%	3	254	0.14%	127	28	1250	1061	34	6	100
Heteropriacanth.	2	2	0.27%	5	159	0.09%	80	86	2000	0	19	4	100
Liza	2	2	0.27%	8	85	0.05%	42	3	1750	354	37	20	100
Priacanthus	2	2	0.27%	4	44	0.02%	22	2	2000	0	17	1	100
Balistapus	1	1	0.13%	5	24	0.01%	24		1500		17		100
Cantherhines	1	1	0.13%	1	67	0.04%	67		2000		36		100
Coris	1	1	0.13%	8	21	0.01%	21		2000		22		100
All the survey[a]	**164**	**742[g]**	**100%[h]**		**185,054**	**100%**	**249**	**106**	**1773**	**482**	**25**	**11**	

[a]Note for Tables 1 and 2: 14[a] sellers have 311[b] tuis containing *Scarus* (S) and 78[c] sellers have 140[d] tuis containing *Chlorurus* (C), which corresponds respectively to 42%[e] and 19%[f] of the total number 742[g] tuis of the survey (100%[h]). Tuis do not contain only one species group. Among the 311[b] tuis, 90[i] contain exclusively *Scarus* (Table 2) and, by subtraction, 221 tuis may contain up to 27[j] different species groups (Table 1). Note that 122 tuis are composed of the two species groups, *Scarus* and *Chlorurus* (for brevity this information is not included in the table). So there are 329 tuis that contain one, the other or both species groups according to the counting rules: $Card(S \cup C) = Card(S) + Card(C) - Card(S \cap C) = 311 + 140 - 122 = 329$. The total number of the tuis is equal to 742[g], 100%[h] of the survey, and not the sum of all the elements of the third column. The same is true for the columns 3 and 4 in Table 1 and the number of sellers in Table 2.

Table 2
Characteristics of the single species group tuis observed in the survey.

Species group *j* (by decreasing number of tuis)	Num. of sellers	Num. of tuis	% of single species group tuis	Num. of tuis Single/ All tuis (%)	% Length of Single Species group tuis/ all tuis	Average Length of species group *j* in single-species group tuis (cm)	SD Length of species group *j* in single-species group tuis (cm)	Average Price of a tui (CFP)	SD Price of a tui (CFP)	**Average Price of species group *j* (CFP/ 10 cm)**	**SD Price of species group *j* (CFP/ 10 cm)**
Scarus	55	90[i]	25%	29%	41%	262	82	1961	154	**84**	**34**
Chlorurus	5	6	2%	4%	16%	264	108	1833	408	**107**	**119**
Parupeneus	4	5	1%	4%	10%	224	91	2000	0	**109**	**64**
Myripristis	18	43	12%	37%	57%	252	106	1977	152	**107**	**88**
Mulloidichthys	6	7	2%	6%	17%	293	90	1857	378	**69**	**27**
Siganus	19	34	9%	33%	52%	239	91	1971	171	**160**	**280**
Pelagic	19	85	24%	94%	91%	169	69	850	533	**62**	**62**
Naso	14	30	8%	35%	53%	120	86	1933	254	**233**	**121**
Epinephelus	2	3	1%	4%	17%	506	233	2000	0	**49**	**30**
Acanthurus	4	7	2%	12%	34%	309	28	2000	0	**65**	**5**
Selar	5	27	7%	90%	94%	271	90	1333	460	**76**	**120**
All the single species groups of the survey[a]	118	361	100%	49%	42.12%	216	107	1620	594		

group with the lowest average price, *Epinephelus* (49 CFP/10 cm) is more than four times less expensive than the species group with the highest price (*Naso*, 233 CFP/10 cm).

Not unexpectedly, prices of single-species group tuis differ from one species group to another. But strikingly, they also differ within each species group, both among sellers and among tuis for the same quantity (length) of fish. Measured by the standard deviation (SD in Tables 1 and 2), these deviations range from 34 CFP for an average price of 84 CFP for *Scarus* to 119 CFP for an average price of 107 CFP for *Chlorurus*, which are the two most frequently encountered species groups in the sample. For *Chlorurus* and two other species groups, *Siganus* and *Selar* (making up a total of 17% of single species group tuis), the deviations are even greater than average prices: by 11%, 175% and 156% respectively. Such price disparities for the same species group between tuis and sellers may relate to the length of the individual fish (consumers may prefer fish pieces of shorter or longer lengths depending on the species groups) and thus to the number of pieces included in the tuis.

Overall, however, the observed price disparities imply the existence of a wide variety of quality attributes of the fish being sold. These attributes may relate to the tuis, their composition in terms of variety of species groups and length of fish offered, but also to the sellers, the fishing techniques used to catch the fish and other determinants of their quality, such as fishing location. Indeed, in addition to the composition and price of tuis, the roadside surveys also collected information regarding the sellers, particularly where and how the fish composing the tuis had been caught, which may directly affect their quality, and hence the price. Table 3 presents the qualitative variables measuring these quality attributes.

Among quality attributes of fish, freshness is a key factor. Local buyers have a keen sense of how long a fish has been out of the water based on the colour of the gills, opacity of the eyes, texture of the skin, flesh and fins, and smell of the entrails, with the key indicators of freshness differing across species groups. Many of these factors, however, are subtle and difficult to generalize. In order to control for these factors involving freshness, roadside sellers were asked in the survey when the fish being sold were caught. However, the time when fish were caught had low variability and a skewed distribution. 83.98% of fishers declared departure time was between 6 pm and midnight, which corresponds to 85.21% of the quantity of fish sold. Most fish were thus taken at night and sold the next morning to ensure freshness at the time of sale. In addition, the low variability of the time when fish were caught is closely linked to many other factors in our empirical model such as "Habitat" and "Boat". Because of these problems of low variability and collinearity with other factors, we do not introduce the time variable in our estimation.

Table 3
Qualitative attributes characterizing the sellers and fish sold.

Variable		**164 SELLERS**		**742 TUIS**	
		n	**%**	**n**	**%**
HABITAT	**LAGOON**	119	73%	561	76%
	REEF	28	17%	104	14%
	PASS	9	5%	29	4%
	OPEN OCEAN	8	5%	48	6%
CREW	**FISH WITH CREW**	101	62%	525	71%
	FISH ALONE	63	38%	217	29%
FISHING GEAR	**SPEARGUN**	136	83%	618	83%
	• with un-motorized boat	*72*	*44%*	*264*	*36%*
	• with motorized boat	*38*	*23%*	*244*	*33%*
	• without boat	*26*	*16%*	*110*	*15%*
	POTI MARARA Fishing	11	7%	72	10%
	LINE	10	6%	26	4%
	• with motorized boat	*9*	*5%*	*24*	*3%*
	NET	7	4%	26	4%
	• with un-motorized boat	*4*	*2%*	*18*	*2%*
BOAT	**WITH MOTOR**	69	42%	379	51%
	WITHOUT MOTOR	67	41%	246	33%
BOAT TYPE	**VAA**	80	49%	334	45%
	• un-motorized	*67*	*41%*	*246*	*33%*
	• low power (≤40 HP) motorized	*13*	*8%*	*88*	*12%*
	POTI MARARA	56	34%	291	39%
	• high power (>40 HP) motorized	*53*	*32%*	*286*	*39%*
	NONE (without boat)	28	17%	117	16%

Fish offered on the tuis came from several different reef habitats. However, the vast majority of landings originated from the lagoon or coral reef areas: 76% of tuis (offered by 73% of sellers) came from the lagoon, and 14% of tuis (offered by 17% of sellers) came from reef areas and the remaining 10% from the pass and open ocean. A total of 38% of sellers had been fishing alone, and were offering 29% of tuis. A large majority of the fish offered had been caught with an average crew of 2 people, but some crews were as large as 7. The two most widely used fishing methods were speargun and polyvalent fishing methods including harpoon and line fishing techniques from motorboats called poti marara, often with powerful motors. Spearguns[10] had been used by 136 sellers (82.93%) to land 83% of the fish offered on tuis; and poti

[10] A skilled spearfisher will shoot fish in particular spots to maintain the fish's aesthetics.

marara fishing had been used by 7% of the sellers to land 10% of the tuis. These are both fairly selective fishing methods. Sellers (80 out of the 164) also used vaas (outrigger canoes), without motors or with very small motors, to catch the fish on offer in 45% of the tuis. In addition, a significant part of the fish sold was caught without a boat: about 16% of tuis consisted of fish caught while swimming from shore by 17% of the sellers. Finally, the survey showed that sellers had only rarely used multiple techniques to catch the fish offered on their tuis.

Additional information regarding the fishing trips was obtained during the surveys of sellers. Table 4 summarizes quantitative attributes of fish catches. A total of 42% of sellers used motor boats with an average engine power of 39 HP. Trip length varied, with an average duration of 6 h. This trip length did not change when sellers used more powerful boats, although it did vary across fishing locations (with shorter trips when fishing in the lagoon and longer (1–2 h) trips when going to the reef and beyond). Only 28 sellers (17%) retained a fraction of their catch before composing their tuis. Their retained catch averaged about one fourth of their total catch (22%), with a maximum value of 62%.

The empirical observations of tui sales derived from the roadside survey summarized in Tables 1–4 highlight a wide heterogeneity in the characteristics of tuis. A modelling approach is thus needed to address these different sources of heterogeneity in order to assess the extent to which changes in the quantities (lengths) of fish of different species groups offered on tuis are likely to affect their price, all else being equal.

3. Hedonic modelling approach

Hedonic modelling is beginning to be applied in seafood studies as for health goods [16], real estate [10], computers [18], and agricultural [35] or environmental goods [11]. This development has been driven by new evaluation questions, relating to the identification of attributes impacting the quality of seafood, as well as their associated monetary value [6,22,28,37]. The approach builds on the observation that on a market, the price of a good is dependent on several attributes that are intrinsic or extrinsic to it, and that measure the level of good quality in its different dimensions. Applications of the approach have thus also relied on the increasing availability of adequate data sets of good quality.

In the case of the Moorea market for fish, since sales are based on the catch of the day and a direct interaction between fishers and fish consumers, demand and supply adjustments can be considered to be very short-term. This is a small-scale subsistence fishery and a closely connected island market of a basic consumption good. Hence it is not surprising to assume in this study that sellers as well as consumers have all and the same information at the moment of the sale.[11] However, demand is expected to be more sensitive to market changes, while supply is constrained by environmental conditions determining access to fishing grounds as well as the productivity of fishing effort, which is in turn related to fish abundance. Given this, the willingness to pay to dispose of an additional quantity of fish of a given species group is expected to be equivalent to observed marginal variations in the (hedonic) price of tuis. Contrary to demand, in the context of Moorea reef fisheries, the supply of fish is considered not flexible enough to follow market variations so that the (marginal) cost of fishing an additional quantity could be equivalent to the variations of (hedonic) prices of tuis. Fishers who sell part of their catch are aware of this and are compelled to compose their tuis and set the tui price taking into account the preferences of local consumers.

Following Rosen [36], we estimate the implicit price of individual species groups of fish encountered on tuis using the two-step hedonic price approach. First we estimate the hedonic price model of tuis and, second, the implicit price model of the fourteen most abundant species groups in our sample. For the purpose of our analysis, we consider a set of intrinsic and extrinsic attributes that have been shown to determine seafood quality in previous studies [13,22,28].

We also considered factors that might affect the quality of the fish of each species group. Ciguatera fish poisoning is an important health and safety issue in coral reef fisheries, including in Moorea [30]. Caused by a toxin that is produced by dinoflagellates and contained in fish tissues, the risk of contamination varies greatly among different taxa of fish. We thus included a qualitative score capturing the absence of risk associated with Ciguatera for a species group j, noted W^j, varying from 40 (high risk of Ciguatera) to 100 (no Ciguatera risk) for each of the 37 species groups (Table 1).[12] The length of the j^{th} species group was weighted by its relative absence of Ciguatera risk $W_{it}^j = L_{it}^j W^j / \sum_{l=1}^{J} L_{it}^l W^l$ combined with the importance of its length L_{it}^j in the tui t of the seller i (L_{it}^l is the length in cm of each l^{th} species group present in this tui). The hedonic price of a tui P_{it} is assumed to depend on the aggregate length of fish $LP_{it} = n_{it} \sum_{j=1}^{37} L_{it}^j \omega_{it}^j$ of all species groups $j = \{1, \dots, n_{it}\}$ composing the tui t of the seller i, weighted by its relative Ciguatera absence score $\omega_{it}^j = W^j / \sum_{l=1}^{n_{it}} W^l$ depending on whether the species group is or is not present in the tui.

According to different studies of seafood products [1,25,28,31,41], the quality of fish products strongly depends on the fishing techniques used to catch the fish. These are considered by both sellers and buyers of fish as indicators of the quality of seafood. In the context of Moorea, as shown in Table 3, fish are largely caught with a speargun. This technique is likely to be perceived as producing high quality fish as it is selective and preserves the fish flesh [32]. The location of the catch, whether from the lagoon or the reef, can also be an additional quality indicator. Tables 3 and 4 summarize the available data regarding these quality attributes of the fish sold.

Using these attributes (represented by the matrix Z), we estimate the following log-quadratic specification of the hedonic tui price equation:

$$\boldsymbol{ln}(\boldsymbol{P}) = \boldsymbol{\alpha_0} + \boldsymbol{\alpha_m} + \boldsymbol{Z\theta} + \sum_j \boldsymbol{\rho_j I^j} + \boldsymbol{\beta_1 LP} + \boldsymbol{\beta_2 LP^2} + \boldsymbol{\varepsilon} \quad (1)$$

This specification enables measuring ρ_j, the equivalent of a lump sum payment incorporated in the price of tui containing the individual species group j, provided it is present in the tui ($I_{it}^j = 1 \text{ if } L_{it}^j > 0;\ 0 \text{ otherwise}$) regardless of the quantity available. Fixed effects are also introduced when estimating the model in order to account for the potential

Table 4
Quantitative attributes characterizing the sellers.

Variable	Definition	% of non-zero	Average	*(SD)*	Max
HP	Engine power (HP)	42%	39	*(21)*	125
CREW	Number of crew	61.59%	1.87	*(1.25)*	7
HOUR FISH	Hours fishing	100%	6	*(3)*	17
FRAQ KEPT	Fraction of catch kept for family and friends (not sold)	17%	22%	*(13)*	62%

[11] Some authors introduce more adequate econometric methods to deal with asymmetric information with seller overestimating and consumer underestimating price [5,19].

[12] The scores were established based on expert knowledge of researchers from CRIOBE (Centre de Recherches Insulaires et Observatoire de l'Environnement, www.criobe.pf). Although ciguatera risk can vary spatially somewhat around the island, for our analyses we applied the same risk factor to a species regardless of where it was caught because finer-scale risk patterns have not been quantified for Moorea.

existence of temporal trends α_m, or other sources of unobservable heterogeneity between tuis or sellers.[13]

The Rosen two-step evaluation procedure consists of deriving the purchaser willingness to pay $\widehat{PWP}^j_{it}$ for a marginal increase in length of each species group *j* from the derivative of the tui's hedonic price, as follows:

$$\widehat{PWP}^j_{it} = \widehat{P}_{it}\omega^j_{it}(\widehat{\beta}_1 + 2\widehat{\beta}_2 LP_{it}) \quad (2)$$

Following standard recommendations of Heckman et al. [14] and the pioneering studies of Griliches [12], Freeman et al. [11] and Mäler and Vincent [27], three methods are used to identify such demand functions for each species group *j* in the Rosen two-stage model.

First, the estimation relies on flexible non-linear specifications with changes in the functional form of the hedonic tui price and the demand functions of each species group. The hedonic price of the tui is assumed to be a log-quadratic function of its aggregated length (Eq. (1)) while, the demand function of the j^{th} species group is a translogarithmic function [4] of the length of all the species group present in the tui (Eq. (3)):

$$ln\left(\widehat{PWP}^j\right) = \alpha^j_0 + \alpha^j_m + Z\theta^j + X\delta^j + \sum_{k\neq j}\rho^j_k I^k + \sum_{l=1}^{J}\beta^j_l ln(L^l) + \quad + \sum_{l=1}^{J}\beta^j_{kl} ln(L^j) ln(L^l) + \mu^j \quad (3)$$

where *X* is the matrix summarizing the available demand factors (see below).

Second, the species group demand function (Eq. (3)) is estimated in the second-stage with a stratified sample database containing the species group under consideration while the first-stage model is estimated using the entire data set. The third column of Table 1 shows that all species groups are not present in all tuis. The first fourteen species groups in the table occurred most frequently in this market, such as *Scarus* which is present in 42% of the tuis (see next section).

Third, identification is based on geographical demand factors (named *X* in Eq. (3) and described in Table 5) characterizing the demand for fish in the different locations based on where each tui was sold. We distinguish the five municipalities of Moorea using a municipality fixed effect[14] and a set of proxy variables to measure purchasing power in each municipality, such as unemployment rate, population density and population change [3]. Indeed, these proxies show that the five municipalities differ in some characteristics, which may directly affect the local demand for fish.[15]

Other proxies are also used to account for the impact of the fish supply differentiation operated by sellers in this market. Three variables are calculated from the database (Table 6), which correspond to the number of tuis (NTUIS) and the total number of species groups (NSPECV) offered by each seller, as well as the total number of species groups in each tui (NSPECT). The two first variables vary in one dimension, between fishers, and the third in two dimensions, between fishers and tuis. Indeed, 50% of fishers offer more than 3 tuis (some of them up to 23 tuis) while the number of species groups varies from 5 to 14 between sellers and from 2 to 9 among the tuis of individual sellers.

As for the hedonic price of tuis, species group pricing strategies have a quantitative dimension in the demand function (*i.e.*, the price and length of fish offered), as well as a qualitative dimension: sellers can combine species groups *j* in variable proportions. To capture this, the binary indicator $I^k_{it} = (1, 0)$ is included in the model, specifying that the k^{th} species group *(k = 1,.,J; k ≠ j)* is present in the tui with the j^{th} species group, in addition to its length L^k_{it}.

The final step in Rosen's model is a monetary evaluation of the additional length (quantity) ΔL of individual species group *j* in the tui using the estimated demand function. This amount is equivalent to the sum of the purchaser's willingness to pay for this additional quantity using the estimated Eq. (3). Represented by $p^j(L^*)$, this is the price in CFP of an additional length ΔL taken to be 10 cm, or one extra piece of fish, as follows:

$$p^j(L^*) = \int_{L^*}^{L^*+\Delta L} \widehat{PWP}^j(x)dx \quad (4)$$

This price is not a fixed amount but varies according to the length of the tui because of the flexibility of the estimated demand function (Eq. (3)). We calculate this price for a fixed reference length of each species group *j, L* =100 cm,* which is the per tui median length encountered for the fourteen most frequent species groups in this market.

4. Results

Applying least square estimation of Eq. (1) and the backward step-wise selection procedure of significant variables, we find that several factors have decisive effects on tui prices that seem consistent with the reality of the market (Table 7 and commentary below). The overall level of reliability of the results is relatively high: the empirical model offers significant explanatory power of tui price variations, with an overall coefficient of determination between 64% and 76%, and its level of reliability exceeds 99.9% based on the Fisher test.

However, there is reason to doubt the exogeneity of two of the explanatory variables. These relate to the fraction of the catch retained by the seller for his personal use (KEPT_UN, a binary variable which identifies sellers who keep part of their catch for themselves, and FRAQ_KEPT, the share-in percentage of this fraction). It is possible that this fraction is kept because of the value of the fish and the species group landed. These variables therefore relate to decisions that are specific to sellers (to retain part of the catch, and how much), and may not be independent of the price of the tuis offered for sale. Carrying out the Hausman test (using its Nakamura and Nakamura version) confirms this. To correct the ensuing endogeneity bias, we use a 2SLS method retaining four instrumental variables in addition to the significant explanatory variables. These instruments provide information on the standard of living in the geographical areas where sellers sell the tuis (usually close to their home), measured *via* levels of unemployment as well as the demographic weight of the municipality (respectively UNEMPL and POIDEMOG in Table 5) and variables capturing the diversity of catches

[13] Other fixed effects parameters were tested during the estimation process, in order to take into account disparities between tuis of each fisher, including the location of sales considered at different scales, but these proved not statistically significant.

[14] Each municipality is represented by a dummy variable. One of the five municipalities is excluded in the estimation as a reference modality. This statistical precaution is respected for all the other binary variables.

[15] Eqs. (1) and (3) are estimated with Stata16 software. All available factors are introduced using a stepwise estimation approach with backward selection, only the variables with statistically significant parameters at the 90% confidence level are retained in the final model.

Table 5
Geographical demand factors.

Municipal.	Sellers		Tuis		POP	POPVAR	SURFACE	DENSITY	POIDEMOG	UNEMPL
	n	(%)	n	(%)	Population in 2012	Population growth between 1977 and 2012	Area in km^2	Population density per km^2	% of municipality in total population 2017	Unemployment rate in 2012
Afareaitu	229	*(30.86%)*	69	*(42.07%)*	3455	277.50	23.80	145.20	21.04	33.80
Paopao	305	*(41.11%)*	40	*(24.39%)*	4580	271.00	30.00	152.70	26.56	15.60
Haapiti	106	*(14.29%)*	32	*(19.51%)*	4062	352.30	38.80	104.70	24.36	21.60
Papetoai	80	*(10.78%)*	16	*(9.76%)*	2318	339.90	25.10	92.40	13.34	26.80
Teavaro	22	*(2.96%)*	7	*(4.27%)*	2484	311.30	15.80	157.20	14.70	21.80
Total	742	*(100%)*	164	*(100%)*	31,199	80,139	27,99	132,4993		23,47

Table 6
Definition and descriptive statistics of supply differentiation instruments.

Variable	Signification	Mean	*(SD)*	Median	Max
NTUIS	Number of tuis of each seller	4.52	*(3.60)*	3	23
NSPECV	Number of species groups of each seller	5.29	*(3.44)*	5	14
NSPECT	Number of species groups in each tui of each seller	2.08	*(1.41)*	2	9

Table 7
Estimated hedonic price function of tuis (Eq. (3)): 2SLS method *vs* OLS.

	VARIABLES	Statistics Mean	SD	OLS β: Param.	*(p value)*	2SLS β: Param.	*(p value)*	Price Index e^{β} or Elasticity*
Length	L	249.4	106.0					
	LP	252.6	109.9	N.S.		N.S.[a]		
	LP^2	75,877	65,450	4.32e-07	*(0.000)*	4.83e-07	*(0.004)*	7.16%*
Species group	*Chanos (1 vs. 0)*	0.00270	0.0519	-0.515	*(0.000)*	-0.535	*(0.005)*	59%
	Monotaxis (1 vs. 0)	0.0229	0.150	0.0930	*(0.077)*	N.S.		
	Mulloidichthys (1 vs. 0)	0.146	0.353	-0.0517	*(0.022)*	-0.0840	*(0.003)*	92%
	Pelagic *(1 vs. 0)*	0.121	0.327	-0.594	*(0.000)*	-0.597	*(0.000)*	55%
	Tylosurus (1 vs. 0)	0.00943	0.0967	-0.650	*(0.000)*	-0.622	*(0.000)*	54%
Trend	February (1 *vs.* 0)	0.0741	0.262	-0.0993	*(0.002)*	-0.224	*(0.000)*	80%
	July (1 *vs.* 0)	0.164	0.371	-0.187	*(0.000)*	-0.166	*(0.000)*	85%
	September (1 *vs.* 0)	0.131	0.337	-0.120	*(0.000)*	-0.194	*(0.000)*	82%
	October (1 *vs.* 0)	0.0606	0.239	-0.0691	*(0.052)*	-0.170	*(0.000)*	84%
	November (1 *vs.* 0)	0.0916	0.289	-0.0634	*(0.032)*	-0.154	*(0.000)*	86%
	December (1 *vs.* 0)	0.0566	0.231	-0.277	*(0.000)*	-0.337	*(0.000)*	71%
Crew and hour fishing.	ALONE *(1 vs. 0)*	0.292	0.455	0.212	*(0.000)*	0.167	*(0.000)*	118%
***x0*= 2.62**	CREW	1.511	1.563	0.237	*(0.000)*	0.204	*(0.000)*	
	CREW^2	4.721	9.209	-0.0451	*(0.000)*	-0.0399	*(0.000)*	
	HOUR_FISH	5.757	2.948	-0.0056	*(0.043)*	-0.0095	*(0.007)*	
Gear	LINE *(1 vs. 0)*	0.0499	0.218	0.124	*(0.003)*	0.137	*(0.011)*	115%
	SPEARGUN *(1 vs. 0)*	0.833	0.373	0.102	*(0.001)*	N.S.		
Boat and HP	BOAT_POTI *(1 vs. 0)*	0.392	0.489	0.350	*(0.002)*	0.354	*(0.013)*	142%
	MOTOR *(1 vs. 0)*	0.511	0.500	0.225	*(0.000)*	0.122	*(0.054)*	113%
	POWER>40 HP *(1 vs. 0)*	0.385	0.487	0.494	*(0.000)*	0.584	*(0.000)*	179%
	HP	18.89	23.78	-0.0392	*(0.000)*	-0.0403	*(0.000)*	
	HP^2	921.6	1680	0.000243	*(0.000)*	0.000243	*(0.000)*	
Endogeneity bias correction	KEPT_UN* *(1 vs. 0)*	0.173	0.215	0.158	*(0.000)*	0.560	*(0.000)*	175%
	FRAQ_KEPT*	0.0315	0.0837	-0.704	*(0.000)*	-2.367	*(0.000)*	
	Constant			7.349	*(0.000)*	7.524	*(0.000)*	
Test statistics	R^2 (R^2aj)			76.1% (75.3%)		64.4% (63.1%)		
	F			91.26	*(0.000)*	60.37	*(0.000)*	
	Sargan test					1.364	*(0.243*	

[a]*p value* of bilateral Student test exceeding 10%.

measured by the number of species groups available from each seller (Table 6) and whether or not the seller is the fisher who caught the fish being sold (79.88% of sellers are the fisher). The estimated auxiliary equation using a 2SLS method shows that most of these instruments have significant impact on the endogenous factor FRAQ-KEPT. In addition, performing the Sargan over-identification test confirms the validity of these instruments.[16]

Results from the estimation of Eq. (3) with OLS and 2SLS are presented in Table 7. Given the endogeneity problem mentioned above, only the 2SLS estimation is considered hereafter. The Price Index column of the table gives the value of the tui price index for each category of the binary variables and the marginal/elasticity effect for the quantitative explanatory variables.

After correcting the endogeneity bias, we note that the price of tuis is 175% higher on average for sellers who retain a share of their catch for their consumption. However, this price drops as the retained share increases, which may be related to the fact that the most highly priced fish

[16] The significance level of this test is 24.30%, for the null hypothesis not to be rejected.

are those that are retained by the sellers first.

The price of a tui is an increasing function of its length. This function is quadratic: the price increase is steeper for longer tuis. The price elasticity is 7.16% for a tui of average length (252 cm), but varies according to the different factors introduced in the model.

Our results indicate that of the 37 species groups that compose tuis, the presence of four[17] has a fixed effect on tui prices. Based on parameter values, the price of a tui is lower if it contains *Chanos*, *Mulloidichthys*, Pelagic taxa and *Tylosurus*; the tui price index decreases on average to 59%, 92%, 55% and 54% respectively in these cases (last column in Table 7). Two of these species groups (*Chanos* and *Tylosurus*) are rare in this market, representing only 0.4% of the total length of all of the 37 species groups (Table 1).

The results also reveal the existence of monthly fixed effects with lower prices of tuis in the months of February, July, and the last four months of the year. As reported by Graddy [43], these seasonal variations may highlight a strong dependency of the fresh seafood market on the suitability of sea conditions for fishing as well as temporal differences in the amount of time available for fishers to participate in the fishery (relative to other activities).

In addition, fishers who sell fish they caught on their own or with smaller crew have tuis with higher prices (price index up to 118%). The price of tuis increases with crew size, up to a point (crew of 3) after which it decreases. Tui prices appear to be higher if they are composed of fish caught with selective fishing gear such as line (price index up to 115%) and motorized boats such as poti marara (price index up to 142%). The price of tuis also depends on the power of the motors on boats, in the shape of a convex polynomial function with a minimum of 83 HP.[18] Hence, tui prices are higher when the fish have been caught either with small or unmotorized boats, or with boats with powerful motors. Tui prices are lower for fish caught with boats of intermediate horsepower (80 HP).

4.1. Implicit price of the most frequent species groups

To estimate the demand function with Eq. (3), we first stratify our database to form subsamples of tuis containing each species group. This stratification shows that the first fourteen species groups in Table 1 (*Scarus* followed by *Chlorurus*, *Parupeneus*, *Myripristis*, *Mulloidichthys*, *Siganus*, Pelagic taxa, *Naso*, *Epinephelus*, *Acanthurus*, *Cephalopholis*, *Sargocentron*, *Lutjanus* and *Selar*) are the most abundant, representing 95.85% of the total length of all the fish present on the 742 tuis. Only these species groups have large enough subsamples to obtain reliable estimates. These fourteen species groups are ranked in Table 8 from right to left in descending order of the number of tuis in which they are encountered. The size of these subsamples varies from 311 to 30 tuis. The most abundant species group is *Scarus* (in 311 tuis) followed by *Chlorurus* (in 140 tuis) and *Parupeneus* (in 130 tuis), while *Lutjanus* and *Selar* are rare (in 30 tuis only).

Tuis can contain up to nine different species groups and half of the sampled tuis (51.28%) contain at least two species groups. Table 8 shows the structure of species group combinations on the tuis. Some species groups are more often combined for sale than others. Two species groups, Pelagic taxa and *Selar*, are crossed with very few other species groups: *Selar*, present in only 30 tuis is combined with two other species groups only (*Lutjanus* and Pelagic).

Pelagic taxa are sold with four other groups (*Myripristis*, *Selar*, *Siganus* and the unidentified species group). The other 12 species groups (in grey in Table 8) are often combined with a large number of other species

Table 8
Species groups combinations on tuis.

	Scarus	*Chlor.*	*Paru.*	*Myri.*	*Mull.*	*Siga.*	*Naso.*	*Epine.*	*Acan.*	*Ceph.*	*Sarg.*	*Lutj.*	*Pela.*	*Sela.*
Number of tuis	311[a]	140	130	115	108	104	85	73	58	55	52	30	90	30
Number of species groups	27[b]	21	25	28	27	24	21	22	21	21	24	20	4	2
Scarus		122 (0.87)	64 (0.49)	18 (0.16)	53 (0.49)	22 (0.21)	16 (0.19)	26 (0.36)	25 (0.43)	23 (0.42)	18 (0.35)	12 (0.4)	0 (0.00)	0 (0.00)
Chlorurus	122[c] (0.39[d])		22 (0.17)	4 (0.03)	15 (0.14)	12 (0.12)	8 (0.09)	10 (0.14)	10 (0.17)	7 (0.13)	4 (0.08)	6 (0.2)	0 (0.00)	0 (0.00)
Parupeneus	64 (0.21)	22 (0.16)		19 (0.17)	72 (0.67)	20 (0.19)	20 (0.24)	26 (0.36)	20 (0.34)	20 (0.36)	15 (0.29)	10 (0.33)	0 (0.00)	0 (0.00)
Mulloidichthys	53 (0.17)	15 (0.11)	72 (0.55)	14 (0.12)		13 (0.13)	10 (0.12)	24 (0.33)	16 (0.28)	17 (0.31)	13 (0.25)	7 (0.23)	0 (0.00)	0 (0.00)
Epinephelus	26 (0.08)	10 (0.07)	26 (0.2)	22 (0.19)	24 (0.22)	12 (0.12)	8 (0.09)		14 (0.24)	40 (0.73)	16 (0.31)	12 (0.4)	0 (0.00)	0 (0.00)
Acanthurus	25 (0.08)	10 (0.07)	20 (0.15)	13 (0.11)	16 (0.15)	16 (0.15)	14 (0.16)	14 (0.19)		10 (0.18)	7 (0.13)	4 (0.13)	0 (0.00)	0 (0.00)
Cephalopholis	23 (0.07)	7 (0.05)	20 (0.15)	14 (0.12)	17 (0.16)	9 (0.09)	1 (0.01)	40 (0.55)	10 (0.17)		13 (0.25)	5 (0.17)	0 (0.00)	0 (0.00)
Siganus	22 (0.07)	12 (0.09)	20 (0.15)	21 (0.18)	13 (0.12)		17 (0.2)	12 (0.16)	16 (0.28)	9 (0.16)	14 (0.27)	3 (0.1)	2 (0.02)	0 (0.00)
Myripristis	18 (0.06)	4 (0.03)	19 (0.15)		14 (0.13)	21 (0.2)	17 (0.2)	22 (0.3)	13 (0.22)	14 (0.25)	27 (0.52)	9 (0.3)	1 (0.01)	0 (0.00)
Sargocentron	18 (0.06)	4 (0.03)	15 (0.12)	27 (0.23)	13 (0.12)	14 (0.13)	5 (0.06)	16 (0.22)	7 (0.12)	13 (0.24)		3 (0.1)	0 (0.00)	0 (0.00)
Naso	16 (0.05)	8 (0.06)	20 (0.15)	17 (0.15)	10 (0.09)	17 (0.16)		8 (0.11)	14 (0.24)	1 (0.02)	5 (0.1)	6 (0.2)	0 (0.00)	0 (0.00)
Lutjanus	12 (0.04)	6 (0.04)	10 (0.08)	9 (0.08)	7 (0.06)	3 (0.03)	6 (0.07)	12 (0.16)	4 (0.07)	5 (0.09)	3 (0.06)		0 (0.00)	2 (0.07)
Pelagic	0 (0.00)	0 (0.00)	0 (0.00)	1 (0.01)	0 (0.00)	2 (0.02)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)		1 (0.03)
Selar	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	2 (0.07)	1 (0.01)	

Explanation of the data: 311[a] tuis contain *Scarus* (2nd line). *Scarus* is combined with 27[b] other species groups (3rd line). *Scarus* is combined with *Chlorurus* in 122[c] tuis, which corresponds to 39% of the subsample of 311 tuis of *Scarus* (the matrix).

[17] There is a fifth species group (*Monotaxis*) present in 2.29% of our sample, which seems to be the only species increasing the value of tuis (it increases prices by 106%) but the estimated parameter is not statistically reliable after correcting for endogeneity.

[18] $\ln \widehat{f_0(P)} = 7.524 - 0.0403HP + 0.000243HP^2$

groups (between 20 and 28 of the 37 species groups present in the market). For example, the most abundant species group, *Scarus*, is combined with 27 other species groups, while *Myripristis* is with 28 (Table 8, Line 3). The second most frequent species group, *Chlorurus,* is pooled on 122 tuis together with *Scarus*, but only on 4 tuis together with *Myripristis*. Note that *Naso* is combined with *Cephalopholis* only on one tui. This structure of species group combinations provides information on the degree of dependence between different groups in the composition of tuis.

To account for cross-species group elasticities within the same tui, we introduce in the model of each of these fourteen species groups, the lengths of the other species groups, as well as a binary indicator of their presence in individual tuis. However, the tuis in each sample do not contain all possible combinations with the other 37 species groups in the database. The most frequent combinations are only between the fourteen most frequent species groups and between a subset of these for some species groups. In the subsample of tuis of the most frequent species group, *Scarus* is combined with *Chlorurus*, *Parupeneus*, *Mulloidichthys*, *Epinephelus*, *Acanthurus*, *Cephalopholis* and *Siganus* in respectively 39%, 21%, 17%, 8%, 8%, 7% and 7% of the 311 tuis. In estimating the model of the implicit price of *Scarus*, we only introduce these seven species groups in order to identify the corresponding parameters. We do the same for each of the other 14 species groups. Table 9 gives cross-elasticities for only those combinations of species groups that are observable and frequent enough among the tuis.

Using Rosen's second stage (Eq. (3)), we estimate the demand functions for the fourteen most abundant species groups (Table A1 in the Supplementary Material). We limit this analysis to these fourteen species groups, because they are the only ones with sufficient sample size. Additionally, the demand factors needed to identify these functions only have a discriminating effect for these fourteen species groups, with their parameters having statistically significant and reliable values. In estimating the demand functions, we also correct for the endogeneity problem of the explanatory variable FREQ_KEP, by the use of a double least squares estimation procedure (as in the hedonic price estimation), and for the problem of collinearity between the explanatory variables by stepwise elimination of variables with the highest VIF (all the factors in the estimated models have VIF values below the theoretical reference threshold of 5).

The length combinations of the fourteen species groups whose implicit price models are estimated allow us to identify the signs[19] of cross-price elasticities between these groups (Table 9). These elasticities specify whether the species groups enter into the composition of tuis as complements (+) or substitutes (−). Results show that the elasticities are positive between all reef species and negative between Pelagic taxa and two reef species, *Selar* and *Siganus*. This means that, except for Pelagic taxa which appear as a substitute group[20] for *Selar* and *Siganus,* all the reef species groups enter as complements in the composition of tuis: some with more species groups than others. *Scarus* is combined with ten other species groups; *Parupeneus* and *Myripristis* with eight; *Epinephelus* and *Acanthurus* with six; *Mulloidichthys* and *Siganus* with four; *Chlorurus*, *Naso* and *Sargocentron* with three; *Lutjanus* and *Cephalopholis* with two. Other interaction parameters are not statistically significant (according to Student's bilateral test): the underlying elasticities are therefore not important and the corresponding species groups appear to enter independently in the composition of tuis. *Scarus*, for example, is present independently of *Lutjanus*, *Selar* and *Cephalopholis*, which are rare species groups in our sample. These interactions reflect seller strategies to enhance the value of the fish sold: where cross price elasticities exist, the species groups on offer value gain in the presence of other species groups, except in the case of Pelagic species (which are caught outside the lagoon and reef areas).

Using the estimated demand function of the fourteen most abundant species groups, we calculated their prices according to Eq. (4). The results are illustrated in Fig. 1b, for eleven of the reef-associated species groups.[21]

Fig. 1a shows the price-index of these species groups relative to the price of the most frequent taxon encountered in the survey (*Scarus*). The results highlight strong heterogeneity in the market value across species groups, which varies between 133 and 137 per cent of the market value of *Scarus*. The next most abundant species groups in this market (*Parupeneus*, *Myripristis* and *Mulloidichtys*) have high market value, with a price index varying between 120 and 135 per cent. *Acanthurus* and *Sargocentron* display high price indices (respectively 137 and 133 per cent), but are encountered less frequently in the tuis.

When applied to the average size of individuals encountered in each species group,[22] prices derived from Eq. (4) provide an estimation of the minimum, mean and maximum price one would pay for a single fish of each species group (Fig. 1b). The four species groups most frequently encountered on tuis (*Scarus*, *Parupeneus*, *Myripristis* and *Mulloidichthys*) still appear to be the more valuable (with prices/fish of between 184 and 237 CFP for an additional medium-sized fish measuring between 35.42 and 48.25 cm). *Naso* display the highest prices per fish (274 CFP for a medium-sized fish of 68.50 cm), and is not frequently encountered in the tuis (Table 1). All the other species groups, which are less frequently encountered on this market, present lower prices/fish piece (under 184 CFP/fish of medium size varying between 27.17 and 53 cm). *Selar* and Pelagic taxa present very low prices, in addition to being rare in the composition of tuis.

5. Discussion and conclusion

This research examines the extent to which economic analysis can help explain the patterns of fish sales and fish prices observed in the coral reef fin-fish fishery of Moorea, French Polynesia. We used the data collected in a survey of roadside tui sales around the island to assess the factors contributing to the price at which the tuis are sold, and to deduce the implicit price of different species groups entering in their composition. Our results show that different groups of reef fish attract implicit prices that may vary by a factor of four to five across species groups. In addition to certain species groups, factors that entail higher prices for tuis include a seasonal dimension (higher prices being fetched during the first half of the calendar year), as well as the fishing techniques and other characteristics of the fishing trips such as the size of the crew. Ciguatera risk, by contrast, did not seem to account for price differences between species groups. Furthermore, our results highlight positive cross-price elasticities between many coral reef species groups. In other words, this means that sellers develop strategies to enhance the value of their daily catches through the species mix (except in the case of Pelagic taxa, that are caught outside the lagoon and reef areas).

This fish market can be considered transparent, since the sellers catch the fish they offer close to sale outlets, using local fishing techniques. However, the quality of the fish and therefore their price can also depend on other criteria (that were not measured in the survey). For example, the appearance of fish was not documented in the survey. Data

[19] Price elasticity of species group *j* with respect to a variation in the length of species group *k* available on the tui is $e_{j/k} = \beta^j_k + 2\beta^j_{kk} ln(L^k) + \sum_{l\neq k}^{37} \beta^j_{kl} ln(L^l)$. Given the flexible form of the implicit price equation, this elasticity is not constant, but its sign is easy to determine: it is equivalent to the sign of the parameters.

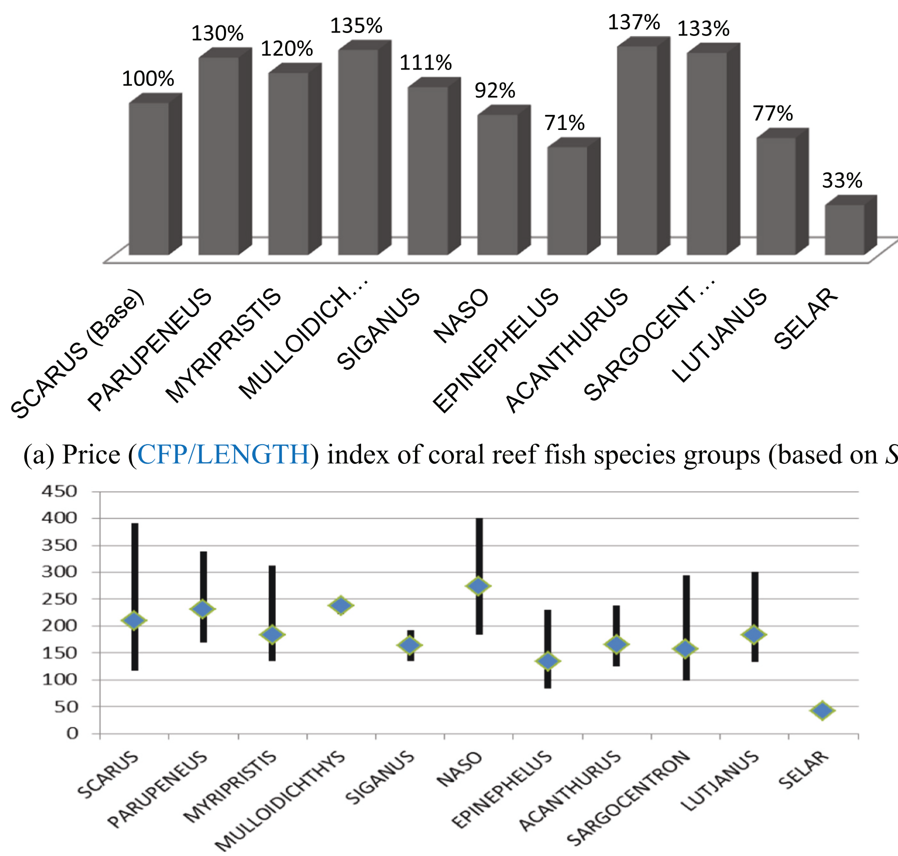
[20] We note in Tables 1 and 2 that Pelagic taxa are often sold alone: 24% of single species group tuis and only 12% of all the survey.

[21] Excluding *Chlorurus* which appeared as an outlier in the price distribution with a price index of 479%. This may have been due to the heterogeneity of the species group, and observation biases.

[22] See Table A2 in the Appendix for data regarding average fish sizes of each species. The medium size of individual fish across all species groups varies between 27.17 and 68.50 cm.

Table 9
Signs of cross-price elasticities between the 14 species groups.

Species groups	*Sca.*	*Chl.*	*Par.*	*Myr.*	*Mul.*	*Sig.*	*Pel.*	*Nas.*	*Epi.*	*Acan.*	*Cep.*	*Sar.*	*Lut.*	*Sel.*	*NI*
Scarus		+	+	+	+	+		+	+	+		+			+
Chlorurus	+				+					+					
Parupeneus	+			+	+	+		+		+	+		+		
Myripristis	+		+			+		+	+	+		+	+		
Mulloidichthys	+	+	+						+						
Siganus	+		+	+			−			+					
Pelagic						−								−	
Naso	+		+	+											
Epinephelus	+			+	+					+	+	+			
Acanthurus	+	+	+	+		+			+						
Cephalopholis			+						+						
Sargocentron	+			+					+						
Lutjanus			+	+											
Selar							−								



(a) Price (CFP/LENGTH) index of coral reef fish species groups (based on *Scarus*)

(b) Price in CFP of mean (min and max)-size fish per species group

Fig. 1. Price estimation results for most frequent coral-reef fish species groups (Species groups are ranked left to right from most to less frequently encountered in the survey). (a) Price (CFP/LENGTH) index of coral reef fish species groups (based on *Scarus*). (b) Price in CFP of mean (min and max)-size fish per species group.

on the physical quality of fish sold, such as traces of handling or state of freshness, are notoriously difficult to observe and measure. Attributes such as the presence of marks due to the fishing method could affect the perception of the quality of fish offered on tuis, leading to bias in the measurement of their implicit prices [33].

Despite these limitations, the results of this analysis illustrate that market processes can help explain the composition and relative prices of tuis offered in roadside sales in Moorea. Taking the observed price differences as a reflection of the preferences of local consumers and associated demand for fish, the results can also be used to assess the economic implications of changes in the supply of the different species groups, such as would result from changes in the abundance and accessibility of these groups to fishers around the island. In particular, Moorea has undergone strong environmental disturbance in its recent past due to the detrimental impacts of blooms of a coral predator sea star and cyclones [20]. Although most of the effects on fish resulted in biomass transfer within functional groups [21], the marine ecosystems presented a recovery debt [9] and understanding how fishermen respond and adapt, and how this translate into changes into how fish are sold remain unresolved.

In addition, the results provide important information on the status of the market for fish on the island. Fish buyers are willing to pay more for extra quantities of fish. This implies that the demand is not completely met by the supply of fish from the local fishery. Besides, the fish demand is expected to grow with an increasing number of new inhabitants less involved in fishing activities themselves [39]. Provided the local fish resources enable additional catch and landings, this market would be expected to expand over time.

Finally, our results show how these fishers value their coral reef fish species on a local and direct sale market. This should be complemented by an analysis of the costs of fishing to gain a comprehensive economic perspective of small-scale fishing activities in Moorea. Beyond this case study, the research also illustrates how empirical economic research can help improve the understanding of small-scale coral-reef fisheries, and demonstrates a methodology which can be applied to a broad range of contexts in the Pacific, where these fisheries have particularly strong social and cultural value, provided similar data on fish sales are available.

Authors statement

A. Nassiri, O. Thébaud, S.J. Holbrook, M. Lauer, A. Rassweiler, R.J. Schmitt and J. Claudet conducted an econometric study based on data collected through a survey on the island of Moorea during 2014–15. The study is based on de Rosen's two-step hedonic pricing method. It allows us to deduce the value scale of several reef species from the distribution prices of tuis.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2021.104525.

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Further reading

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