Putting Economics into Maximum Economic Yield

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ABSTRACT
Maximum economic yield (MEY) can be extended along two dimensions beyond the common resource stock externality: (1) the appropriate measurement of costs and benefits and (2) extending MEY beyond the relationship between the harvest sector and the resource stock externality. Only when all economic distortions are accounted for and valued by economic (shadow) prices does MEY actually represent a full economic optimum. Accounting for dynamic technical and allocative efficiency extends MEY beyond the traditional dynamic scale efficiency. When accounting for accumulated and new technology and nonmarket public good benefits from biodiversity and ecosystem services, an open question remains whether the MEY resource stock exceeds, equals, or falls short of the MSY resource stock. Without no-growth, steady-state equilibrium, adaptive management is required using non-autonomous bioeconomic models or continuous updating of autonomous ones.

Key words: Maximum economic yield, economic efficiency, equity, economic and social prices, public goods, technical change, numeráire, fisheries.
JEL Codes: Q22, Q27, D61, D62.

INTRODUCTION

The concept of maximum economic yield (MEY) and its relationship to maximum sustainable yield (MSY) continues to generate considerable debate, and as this article shows, the debate is not yet over. Two general themes remain open to further development: (1) the appropriate measurement of costs and benefits in estimates of MEY and (2) the need to extend MEY beyond the relationship between the harvest sector and the common resource stock externality. Only when these factors are incorporated into MEY does MEY represent a full economic optimum.

The MEY numeráire of monetary values (hereafter present value, real—constant—dollars, and units of domestic currency as a minimum component of the numeráire) allows aggregation of net benefits from the vessel level through the value chain and consumers and extends beyond the species of concern and the resource stock externality to pure and impure public goods.[1] The use of economic (efficiency) prices accounting for economic efficiency revises the

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1. The numeráire in the standard approach to applied welfare economics is most broadly consumption in the present period, where consumption can be thought of as a composite of the consumption of all goods and services measured by the real income required to purchase them (Boadway 1976; Ray 1984).

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numeráire from simply dynamic MEY measured in financial prices.[2] The use of economic prices for labor allows incorporating the social objective of employment and secondary benefits (indirect effects). Explicit consideration of income distribution and application of welfare weights conceptually and quantitatively incorporate the social objective of income distribution into a single quantitative measure, MEY, through social prices that reflect both efficiency and equity (Little and Mirrlees 1974; Squire and van der Tak 1975; Adler 2013), rather than broad and qualitative modifications of MSY (cf. Hilborn 2007). Policy makers receive a single quantitative measure of the socially optimum resource stock incorporating all economic and social concerns in a theoretically consistent manner rather than a measure modified by ad hoc and qualitative adjustments. Explicitly accounting for equity along with efficiency through social prices provides one framework by which to conceptualize social issues, such as the social wellbeing components of sustainability in United Nations resolutions on Ocean Law of the Sea and on Sustainable Fisheries (Rice 2013).[3]

The reasons why fisheries should maximize economic net benefits are broadly recognized. However, only Australia's federally managed fisheries have formally adopted as the target biomass the biomass corresponding to MEY, B_{MEY}, defined in terms of maximum economic rent of the harvesting sector, with present value, domestic currency, and real financial prices comprising the numeráire (Kompas et al. 2010; Smith et al. 2013). The Parties to the Nauru Agreement's Vessel Day Scheme, while not explicitly targeting MEY and B_{MEY}, aim toward maximizing economic rents (cf. Havice 2013). A dynamic bioeconomic model is also currently under development for use by the Western and Central Pacific Fisheries Management Commissions. Increasing rights-based management in fisheries gives further impetus to maximizing economic rents and consideration of MEY and B_{MEY}. While MEY is still not widespread in practice, as nations and fisheries increasingly focus upon maximizing economic benefits from fisheries, better defining and understanding MEY grows in importance.

This article expands MEY by addressing the two themes in four steps. First, we further develop recent extensions of MEY beyond the harvest sector to the value (supply) chain and the consumer (Christensen 2009; Sumaila and Hannesson 2010; Grafton et al. 2010, 2012; Vieira and Pascoe 2013). Second, we develop appropriate measures of economic costs and benefits that allow for economic efficiency by the use of economic (efficiency) prices that account for missing, incomplete, and distorted markets. Financial prices take existing market prices and income distribution as given, based on an accounting perspective of the private firm or consumer, including financial flows. We also consider income distribution (equity) issues through social prices that incorporate welfare weights. Third, we account for the public good of new technology. We also broaden the type of economic efficiency incorporated into MEY from dynamic scale efficiency to dynamic Debreu-Farrell efficiency that now is com-

2. Financial prices are those observed market prices for a financial analysis from the perspective of a private investor as opposed to an economic analysis from the perspective of the society using economic (accounting) prices (Little and Mirrlees 1974; Squire and van der Tak 1975; Boadway 1976; UNIDO 1978; Ray 1984; World Bank 1996; Asian Development Bank 1997). Financial prices include transfers (financial flows without a corresponding flow of goods or real consumption of economic value), including government redistribution activities, principal, and interest, and use observed market prices. Throughout this article, we assume that only a given state and its citizens have standing, unless discussing transboundary resource stocks and related issues, in which case member and cooperating non-member parties (states and territories) to a Regional Fisheries Management Organization or other relevant international organization have standing.

3. In the United States, President Clinton's Executive Order No. 12866 expressly requires US federal agencies to consider distributive impacts and equity and to consider qualitative as well as quantitative factors (Hahn and Sunstein 2002).

prised of dynamic technical, allocative, and scale efficiency. Fourth, we expand the discussion beyond the traditional commons problem and the resource stock externality to account for the public goods of biodiversity and ecosystem services, which include bycatch, and their externalities that grow in importance with ecosystem-based fisheries management. Completing this step allows clarifying and fully specifying the numeráire (unit of account).

We will not discuss the conceptual issues related to MSY and MEY when there are technical and biological interactions. When there are technical interactions and, therefore, production is a multi-output, the yield curves have to be added and total MSY/MEY can be defined, but it might lead to under- and overexploitation of the involved species (Caddy and Sharp 1986; Kasperski 2015). An example could be a mixed groundfish fishery. When there are biological interactions, e.g., predator-prey, there will be a tradeoff curve of yields (like the well-known production possibility curves) and hence multiply MSY levels, but only one MEY-level depending of relative prices and cost, which beside biological conditions also depends on economic parameters such as relative prices and multiproduct costs and the technology of joint production (Flaaten 1988; Kasperski 2015). Nonetheless, we note that these results also depend upon the state of technology, because technological progress can reduce technical interactions by increasing selectivity.

The exposition herein is also explicitly based on surplus production models. However, the results obtained also apply to more complicated single-species biological models; e.g., age-structured models (Tahvonen 2009; Skonhoft, Vestergaard, and Quaas 2012), because the MSY-stock is specified as an optimal stock composition of age-classes, and while more complicated, it does not, in principle, impact our considerations.

The balance of the article is organized as follows. First, the current literature discussing MEY and its relationship to MSY is reviewed. Then the current discussion of MEY from the vessel level through the value chain and the consumer is further developed. Next we introduce the use of economic prices to account for economic efficiency, including accounting for missing, incomplete, and distorted markets and financial transfers, and social prices to account for equity issues. Then the public good of accumulated and new technology and the impact upon MEY is introduced. This is followed by incorporating the public good of biodiversity and ecosystem services, extending the commons problem to account for not only the resource stock externality, but also the public good externality. The final section concludes.

LITERATURE REVIEW

Christensen (2009) asserts that MEY equals MSY, because heretofore MEY only accounted for the fish harvest and excluded the full value-chain impact.[4] Sumaila and Hannesson (2010) in a rejoinder state that MSY differs from MEY, even when the benefits from the complete fish value chain are taken into account. Further, maximizing society's economic benefits comes when resources are allocated across all uses to equalize net benefits from employing one more unit of society's resources. They suggest that when there is excess capacity

4. An anonymous referee notes that Christensen (2009), ". . . asserts that MEY = MSY by making the additional assumption that maximum social value coincides with the largest fleet sector and related value chain impacts, which occurs at MSY catch. Christensen's MEY = MSY is based on an implied social welfare function that places greater value on fleet size than would be justified based on the quantified value chain effects."

in the economy, such that all resources are not fully utilized, the multiplier effect upon incomes and employment from additional rounds of spending and zero pricing of labor could be important. Grafton et al. (2012) show how B_{MEY} can be used to determine relative employment and profitability measures, account for both the harvesting and processing sectors, and incorporate consumer benefits. Grafton et al. (2012) further show that including a processing and/or retail sector along with measures of consumer benefit lowers the B_{MEY}, but that there remains a broad range of parameter values for which $B_{MEY} > B_{MSY,}$ and that B_{MEY} can thereby serve conservation goals. Vieira and Pascoe (2013) survey current issues and question including the value chain up to and including the consumer benefits in MEY. Punt et al. (2013) discuss relative abundance proxies for B_{MSY} and B_{MEY}.

To date, MEY measures have been a combination of both financial and economic valuations of costs and benefits in a static-in-technology fishery and mainly focused upon the supply side and producer benefits (in the form of economic rents) that arise with dynamic scale efficiency and have largely (but not totally) overlooked consumers and nonmarket benefits from public goods of biodiversity and ecosystem services. B_{MEY} and MEY can be found as a solution to a dynamic bio-economic problem that involves the "Golden-Rule" in which the return of one more unit of stock biomass is balanced against harvesting one more unit (Clark and Munro 1975). As such, MEY, to date, has not represented a full economic optimum. Accounting for accumulated and new technology and other sources of economic efficiency; i.e., technical and allocative efficiency (Squires and Vestergaard 2013a,b), consumer welfare (Bulte, Folmer, and Heijman 1998; Clark 2010; Grafton et al. 2012), and nonmarket external benefits (Tisdell 1991; Bulte, Folmer, and Heijman 1998; van Kooten and Bulte 2000)—notably public benefits from biodiversity and ecosystem services, plus valuing costs and benefits by economic prices and accounting for all sources of dynamic economic efficiency gives a full MEY rather than a hybrid financial-economic MEY.[5] Adding processing, distribution, and the retail sector (the value/supply chain) expands MEY beyond the fishery production process to include the entire fisheries sector (Christensen 2009; Sumaila and Hannesson 2010; Grafton et al. 2012, Vieira and Pascoe 2013).

VALUE CHAIN AND CONSUMERS

MEY can capture the total net economic benefits throughout the value chain up to and including consumers. Including a processing and/or retail sector along with a measure of consumer benefits lowers the BMEY target (Grafton et al. 2012).

The derived demand curve for the necessary input fish at the ex-vessel level entering the bioeconomic model can be specified as an inverse general equilibrium derived demand curve (Just, Hueth, and Schmitz 2004). A demand curve for fish is derived at the processing-broker level in the value chain that includes not just the price and quantity of the fish concerned, but the relevant prices or quantities for other species that are substitutes or complements and priced elsewhere in the supply chain. This derived demand is generally specified as price dependent, leading to an inverse rather than direct demand (Barten and Bettendorf 1989).

5. Here we abstract from the population dynamics with contemporary issues, such as uncertainty (Kompas, Che, and Grafton 2008), or meta-populations and patchy stock issues for some benthic and groundfish species with demonstrated density-dependent fish and larval movement (Sanchirico and Wilen 1999), or cyclical populations for small pelagic species (Carson et al. 2010).

This general equilibrium specification for an essential rivalrous input, fish, allows capturing the net private economic benefits of markets in the value chain for rivalrous inputs and outputs and accounts for multiple price changes in multiple markets without path dependency. If the demand curves for multiple markets are not general equilibrium, then changes in Marshallian consumer surplus with price changes in multiple markets differ according to which market's welfare is first assessed, called path dependency. Unlike Marshallian consumer surplus, measures of producer welfare are path independent because they measure profits rather than unobserved utility with budget constraints and income effects.[6] In principle, without appropriate separability assumptions, all important goods and services, not just fish, would have to be included. In the commercial sector, an interrelated set of demand and supply functions is linked through different levels of markets from the vessel level to the final consumer (Thurman and Easley 1992). Harvested fish are then an essential rivalrous input of the processing sector throughout the retail sector to the consumer final demand in the entire value chain.

When properly specified and estimated as Hicksian (compensated) rather than Marshallian (uncompensated), consumer welfare measures are the preferred compensating and equivalent variations. In general, these Hicksian measures are not subject to path dependency with simultaneous multiple price changes or when both income and price change simultaneously (Just, Hueth, and Schmitz 2004).[7] These measures may differ little from Marshallian consumer surplus when the income effect from a price change is small (ideally zero), as expected in many markets, but not for lower income groups, artisanal fishers, or when fish comprises a sizeable part of consumption (Willig 1976; Just, Hueth, and Schmitz 2004).[8]

The Grafton et al. (2012) approach of adding the separable net benefits from the value chain to consumer and producer surplus into the objective function is appropriate when an equilibrium demand curve for fish is not used and there are not simultaneous price changes in multiple markets (Just, Hueth, and Schmitz 2004).

The general equilibrium approach has focused on the value chain of related markets for rivalrous inputs and outputs, but this approach can also be applied to the ecosystem, where there are also up- or downward linkages. Many of the relevant prices will be economic prices that capture non-market economic values. Changes in harvest for one species will, via ecosystem interactions, impact other species and users of the ecosystem. This general equilibrium approach can include biomass changes of the other species, impacts upon food webs, and changes in ecosystem services. An example is the forage fish fishery.

EFFICIENCY AND EQUITY: ECONOMIC AND SOCIAL PRICES

An overlooked issue is the distinction between a private, financial analysis using existing market prices—financial prices—and an analysis that uses shadow (also called accounting or

6. Constancy of the marginal utility of income with respect to the prices and/or income that change guarantees path independence of consumer surplus and that consumer surplus measures utility change (Just, Hueth, and Schmitz 2004).

7. An anonymous reviewer noted that the general equilibrium demand function measures of compensating variation for models based on the synthetic demand system are not path dependent, although measures of both consumer surplus and equivalent variation are path dependent. See Kim (1997) for compensating and equivalent variation with inverse demand systems and multiple quantity changes.

8. Just and Gilligan (1998) demonstrate that Willig's results fail when integrability fails; thus, Willig's rule of thumb is not applicable to ad hoc demand specifications. See Kim (1997) for inverse demand functions and scale (rather than income) effects.

economic) prices.[9] In a very general usage, the shadow price of a good or service is defined in terms of the marginal effect on social welfare of the availability of an extra unit of the specified consumption good or service, output or input, net income, or the economic opportunity cost in terms of social welfare of a marginal unit reduction in production (Drèze and Stern 1990). We distinguish between economic (efficiency) prices and social prices, both of which are specific forms of generic shadow (accounting) prices and that account for economic efficiency and equity (distribution), respectively.

We first consider an economic analysis accounting for economic efficiency using economic prices that account for missing, incomplete, and otherwise distorted markets. Beyond externalities, there can be further distortions in a second-best setting in which private markets are distorted and market prices typically deviate from a full economic optimum; in our case, from MEY representing a full economic optimum. These distortions include: (1) indirect or income taxes, (2) quantity controls, (3) controlled prices, (4) tariffs and trade controls, (5) oligopoly, and (6) imperfect information and transaction costs (Drèze and Stern 1990). Subsidies are negative taxes and are implicitly considered.

The economic price for labor, called the shadow wage rate, measures the economic value to society from the last unit of labor employed in the fisheries sector plus any disutility of worker effort, both measured in economic prices to account for distortions elsewhere in the economy (Squire and van der Tak 1975; Sinden and Thampapillai 1995; World Bank 1996; Asian Development Bank 1997; EPA 2000; European Commission 2008).[10] This shadow wage rate is based upon the economic benefits foregone by labor when employed; i.e., its economic opportunity cost, which accounts for the forgone marginal product; the marginal social value (disutility) of foregone leisure; the value of employment that is not directly paid a wage but contributes to the economy, such as self-employment; the value of unemployment benefits; and other factors, measured in economic prices to account for distortions elsewhere in the economy.

The shadow wage rate also accounts for any government-induced distortions in labor markets, including minimum wage laws, unemployment insurance, income taxes, and legal impediments to labor mobility. Market-induced distortions include union market power over wages or restricted entry into a particular market.

Labor always has an opportunity cost, even if there is high unemployment and idle labor, since people do not work for free, and there is always a forgone output or leisure that forms the reservation wage plus disutility of effort, even if not occurring in a market. Not only might seemingly unemployed labor be employed in the informal economy or be self-employed and/or receive payments in kind, but unemployed labor has a reservation wage necessary to activate the unemployed in any particular area. This reservation wage—the minimum cost of hiring an unemployed person—is the controlling element for a worker with no productive alternative, since he demands a minimum amount as a condition of employment (Powers 1981). In contrast, Sumaila and Hannesson (2010, 2), state, ". . . further activities in the fish value

9. Financial analysis, besides taking markets prices, transfer flows, and externalities as given, and excluding consumer welfare, also uses private interest rates rather than social discount rates and takes the distribution of income as given. The scope and duration of the analysis can differ, and accrual rather than cash flow accounting is often used in financial analysis (discussed in footnote 20).

10. The economic value of disutility of worker effort in economic prices that account for distortions elsewhere in the economy depends on relative employment conditions and whether or not a worker is already employed. This can be measured by the difference between labor's supply price for the new and old jobs (Squire and van der Tak 1975).

chain would not be costs, such as when this would employ otherwise idle labour." Using a shadow wage rate compared to treating unemployed labor as free raises the costs, lowers the net economic benefits and MEY, and should raise BMEY.

The shadow wage rate may be less than the market wage rate or even the crew share, provided that the risk and uncertainty incorporated in the crew share are also incorporated into the shadow wage rate. The economic benefits to society from employing this otherwise unemployed or underemployed labor (and accounting for foregone leisure and self-employment) will be incorporated into the producer benefits that are larger than when measured by existing market prices. An example of this situation can be found in Vestergaard, Stoyanova, and Wagner (2011), where the crew share wages are assessed to be above the shadow wages rate even when adjusted for risk.

The shadow wage rate accounts for any indirect effects—secondary benefits—in the economy from additional employment, such as additional rounds of spending that can occur. These increase income and employment when there is persistent excess capacity in the economy (Little and Mirrlees 1974; Squire and Van der Tak 1975; Boadway 1976; UNIDO 1978; Drèze and Stern 1990; World Bank 1996; Asian Development Bank 1997; European Commission 2008).[11] Employment has indirect benefits through additional rounds of spending from the employed fisheries labor when there is excess capacity.[12] When comprehensive, shadow prices are defined in such a way as to include all the direct and indirect effects; it is not necessary to sum welfare effects in each market and for each agent (Boadway 1976; Drèze and Stern 1990).

The total effect of this chain reaction of spending can be summarized by multiplier analysis of input-output analysis (Sumaila and Hannesson 2010; Norman-López and Pascoe 2011). Nonetheless, "textbook" economic analysis correctly accounts for these economic benefits by using shadow prices for all inputs and willingness to pay or accept to measure consumer benefits (Squire and van der Tak 1975; World Bank 1996; Asian Development Bank 1997; Australia Commonwealth 2006; European Commission 2008).

The use of shadow wage rates to capture secondary impacts of employment—indirect effects—requires additional clarification. If there is persistent excess capacity in the sector and accompanying unemployment, the shadow wage rate is used as just discussed. When the economy is at full capacity or the labor to be used is already fully employed, the project or policy displaces existing labor, which requires use of a demand price rather than the labor supply price (Squire and van der Tak 1975; World Bank 1996; Asian Development Bank 1997; Australia Commonwealth 2006).

Intuitively, indirect effects capture the impact of a policy, not the net-benefit, because the expenses in one part of the economic system are income in another part. Only in the case where there is persistent excess capacity and formerly underemployed or unemployed resources are not utilized, new net benefits are created rather than transfers or effects canceling each other out.[13]

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11. This approach is inherently a partial rather than general equilibrium approach, the latter which is seldom applied in fisheries analyses.

12. Other indirect effects by which a change in the demand for a good or service induces changes in the market output of commodities in other distorted markets are of little concern in most fisheries sectors.

13. One reviewer noted that calculating the induced effect of fishery policy on spending can be difficult, because reduction in employment of a policy may be offset by increased spending of those remaining in the fishery sector.

Shadow pricing is also concerned with traded commodities whose benefits or costs involve a supply or demand for foreign exchange. When calculating MEY for any country with substantially distorted foreign exchange rates due to substantive import and export tariffs, taxes, quotas or multiple exchange rates, among others, the shadow exchange rate (SER) rather than the official exchange rate (OER) should be used to value traded inputs and outputs in the UNIDO approach to project valuation (Little and Mirrlees 1974; UNIDO 1978; Squire and van der Tak 1975; World Bank 1996; Asian Development Bank 1997; European Commission 2008).[14] Inputs and outputs that do not enter into international trade—nontradables—may be shadow priced for domestic market distortions by economic prices (and social prices for equity) but are not shadow priced by the SER.[15] In general, the SER equals the OER only if all trade distortions, such as import duties and export subsidies, are eliminated.

Social prices account for the wider consequences of income distribution in any given time period; i.e., equity concerns and between time periods.[16,17] MEY analyses apply equal welfare weights (also called distributional weights) to all individuals; ports; gear groups; recreational, commercial, and subsistence fishers; regions; social groups; states; or other social units of concern. Equal welfare weights involve interpersonal comparisons of utility; in that regard, the distinction between economic and social prices is a false one (Ray 1984). Nonetheless, we maintain this conventional distinction. A specification of equal welfare weights contains several implicit assumptions, such as marginal utilities of income equal across all individuals, so that the marginal gain in consumer well being (utility) with a one-unit increase in income equates across all individuals or households, regardless of income and wealth levels (Squire and van der Tak 1975; Harberger 1978; Drèze and Stern 1990; Just, Hueth, and Schmitz 2004).[18] Welfare weights take account of the different social value to different individuals from one dollar of real income. The magnitude of the welfare weights depends upon the

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14. An alternative approach, which gives the same relative rankings for alternatives, is the use of conversion factors and border parity prices. This "world price" approach, instead of consumption as the numeráire, specifies foreign exchange in the hands of the government (Little and Mirrlees 1974; Squire and van der Tak 1975). Some developing countries, such as Venezuela and Iran, suffer from substantially distorted OER.

15. The SER is an economic price that differs from the official price of foreign exchange by the amount of the foreign exchange premium. The SER is the value of an additional unit of foreign exchange that accurately reflects the consumption value of an extra unit of foreign exchange in terms of the domestic currency, given the trade policies that are expected to prevail over the life of the project (UNIDO 1978). The SER may be calculated as the weighted average of the demand price (for displacement of foreign exchange from current uses) and supply price (for increased availability of foreign exchange) of foreign exchange to the country, although there are other approaches based on average, rather than marginal, conditions using average imports, exports, subsidies, and taxes.

16. Income distribution between current and future time periods; i.e., savings, investment, economic growth, and future consumption, is accommodated by different relative weights for savings/investment and consumption. See Little and Mirrlees (1974); Squire and van der Tak (1975); Ray (1984); and Adler (2013). Although not implemented in practice, in principle differential weights are given to the incremental net benefits received by the private and public sectors (the latter which is assumed to have a higher marginal propensity to save and account for capital market distortions and the marginal cost of public funds due to the marginal deadweight loss of raising public funds). This topic is not considered here.

17. Measuring the net benefits over time as the time path of total real consumption aggregated over individuals in the economy can be replaced by real income (the MEY approach now followed in principle) rather than consumption, since consumption and savings (private and public) can be restated in terms of real income (Squire and van der Tak 1975, Boadway 1976, Ray 1984). The net effects on real income can be measured as the sum of equally weighted consumer and producer surpluses (the MEY approach). This raises two issues: Valuing the gains and losses accruing to an individual and aggregating them over individuals both at a point in time and over time. The subject of social prices addresses valuing and aggregation gains and losses at a point in time. Considerations of different points in time raises the issue of savings and consumption discussed in the previous footnote (and also in principle entering social prices), the choice of social discount rate, and inflation, all of which are beyond the scope of this article.

18. Alternatively, individual utility functions can be assumed quasilinear in some consumption goods, so the marginal utility of income is constant (Boadway and Bruce 1984).

form of the social welfare function, which, in turn, requires ethical judgments on how to aggregate individual utilities and reflects the willingness to trade off the utility or well being of one individual against another (Layard and Walters 1994; Londero 1996). We do not discuss this particular aspect of welfare weights any further except to define a social price as the marginal change in the social welfare function (which includes welfare variables defined over economic agents) for changes in net production or consumption or income distribution, so that social prices incorporate equity and efficiency issues through the social welfare function.

CHANGES IN TECHNOLOGY AND OTHER SOURCES OF ECONOMIC EFFICIENCY

Unless a fishery is absolutely devoid of changes in technology, the environment, or relative prices, the relationship between MEY and MSY is unclear. This relationship changes over time; i.e., there is *not* a no-growth, steady-state equilibrium, and analysis requires non-autonomous bioeconomic models.[19] Moreover, dynamic MEY has only considered one source of dynamic economic efficiency, dynamic scale efficiency, and has excluded dynamic Debreu-Farrell technical and allocative efficiency (Squires and Vestergaard 2013a,b). We define these terms as we discuss them below.

If $\delta > 0$ is a constant denoting the continuous social rate of discount, P denotes a constant real *market* product price, B_t denotes biomass, Y_t denotes yield or catch, t denotes time, q denotes the catchability coefficient, c denotes the constant unit effort cost measured in real *market* prices, λ denotes the rate of disembodied technical change (not embodied in physical capital), M denotes the constant cost share of physical capital, ψ denotes the rate of embodied technical change, $-\mu(t, Z)$ denotes technical inefficiency or the deviation from the best practice frontier that shifts with changes in technology, Z defines a vector of explanatory variables associated with technical inefficiency, and cash flow accounting is used, then the objective is to maximize the discounted present value of real producer benefits from the harvesting sector (Squires and Vestergaard 2013b):[20]

$$PV(\pi) = \int_0^\infty \pi[Y_t, B_t]e^{-\delta t}dt \text{ subject to: } dB/dt = F(B_t) - Y_t \text{ and } B_0 = B(0),$$

where $\pi = \left[P - \frac{c}{qB_t e^{(\lambda+M\psi)t-\mu(t,Z)}}\right]Y_t$ is the producer benefit or economic rent measured in real market prices. Solving this optimization problem leads to sustainable biomass, rent, yield, and effort that varies with changes in technology. Therefore, it does not attain a no-growth, steady-state equilibrium, although it does asymptotically approach a limit stock in which the marginal productivity of the resource stock equals the social discount rate.

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19. Dichmont et al. (2010) advocate constant updating of autonomous bioeconomic models, giving adaptive management, to account for changing market prices. We add to that the need to account for accumulated and ongoing technical change and changes in the environment, especially for small pelagic species and shrimp with regards to changes in the environment.

20. Either cash flow or accrual accounting can be employed (Boadway 1976). These methods differ on the timing of when transactions are credited or debited and are especially important for capital inputs. The cash flow approach does not count an inflow or outflow until it actually occurs (is paid). Notably, capital expenditures are fully expensed when they are made. These include all investment expenditures—additions to a project's capital stock, replacement and depreciation spending, and scrap value salvaged when the project terminates. Costs of financing and ongoing depreciation are not included, since that would be double counting, except to the extent that depreciated capital is replaced. The accrual approach counts an inflow or outflow for an input when the input is actually used rather than when it is acquired. Two costs are included, depreciation and financing. If properly executed, the present value of an investment's accrual costs should equal its cash flow. Accrual accounting is more difficult, since it requires knowledge of depreciation, which cannot readily be observed from market prices.

MEY, as discussed in the literature (see Clark 2010), simply measures dynamic scale efficiency in which the marginal cost of effort equals the marginal benefit of effort. However, two other sources of economic efficiency, technical and allocative, are excluded, giving a mismeasurement of the full dynamic MEY (Squires and Vestergaard 2013b). Full Debreu-Farrell economic efficiency; i.e., technical, allocative, and scale efficiency, is obtained by accounting for technical efficiency in $\pi = \left[P - \frac{c}{qB_t e^{(\lambda+M\psi)t-\mu(t,Z)}}\right] Y_t$ and allowing for allocative efficiency in the aggregator function that forms the composite input index, effort, so that economic costs are minimized in effort's formation[21] and allocative efficiency in the formation of any composite output index, catch, so that economic revenues are maximized.[22]

B_{MEY} can, in many instances, be expected to fall below B_{MSY} over time with the relentless march of technological progress, because technological change lowers the costs to fishers from searching and harvesting fish without leaving fish in the water to lower costs (Squires and Vestergaard 2013a,b). Both accumulated and new technology must be incorporated into MEY.

The Golden Rule for investment, with and without changes in technology or technical efficiency, can be compared to highlight their impact. The Golden Rule for a fishery that is static in technology and prices, allowing for investment in physical capital, and only dynamic scale efficiency can be written (Clark, Clarke, and Munro 1979):

$$\frac{\partial F}{\partial S_t} + \frac{(c_v B_t + c_f(\gamma + \delta))F(S_t)}{(PqS_t - (c_v B_t + c_f(\gamma + \delta)))S_t} = \delta,$$

where the left-hand side is the marginal productivity of the resource stock, the middle term is the marginal stock effect, γ is the depreciation rate, c_v is all costs other than investment (capital costs are rental/Jorgenson-Christensen service prices), and c_f is the fixed cost of investment.

The Golden Rule allowing for accumulated and new disembodied technology, investment in physical capital that embodies new technology, and Debreu-Farrell economic efficiency can be written (Squires and Vestergaard 2013b):

$$\frac{\partial F}{\partial S_t} + \frac{(c_v B_t + c_f(\gamma + \delta))F(S_t)}{(PqS_t e^{(\lambda+M_2\psi)t-\mu(t,Z)} - (c_v B_t + c_f(\gamma + \delta)))S_t} + \frac{(c_v B_t + c_f(\gamma + \delta))(\lambda + M_2\psi - \partial\mu(t,Z)/\partial t)}{PqS_t e^{(\lambda+M_2\psi)t-\mu(t,Z)} - (c_v B_t + c_f(\gamma + \delta))} = \delta.$$

The second term from the left is the modified marginal stock effect, and the new term is the marginal technology effect. Technical progress now lowers the search and harvest costs, so fewer fish need to be left in the water to lower costs, and the relative importance of the marginal stock effect declines. Relative prices and costs can also change over time (Clark and Munro 1975; Clark 2010).[23] Technical efficiency allows for falling behind and catching up to the changing best practice frontier.

21. Ratios of marginal products to corresponding ratios of input economic—not necessarily market—prices are equal in the effort aggregator function of a two-stage production process.

22. Ratios of marginal rates of product transformation equal corresponding ratios of economic—not necessarily market—prices in the output aggregator function of a two-stage production process.

23. Whether or not there is rising marginal cost of effort at low resource stock levels is an empirical question. One factor militating against this is an exponent of one on the rivalrous composite input index, effort, which is expected if the aggregator function for effort is linearly homogeneous in construction as required for a homothetically separable composite rivalrous input, here effort. Product prices could also rise with increasing scarcity of the resource stock and landings, depending upon substitution possibilities, income effects, and the extent to which the fish is traded.

No-growth, steady-state equilibrium MEY estimated from a non-autonomous bioeconomic model and the Golden Rule provides an economic target that does not exist—unless the fishery is not subject to the forces of technological change and markets are constant. Imposing no-growth, steady-state equilibrium MEY creates a widening gap over time between the autonomous scale-efficient MEY and non-autonomous Debreu-Farrell efficient MEY and creates increasing foregone net economic benefits due to erroneous management, leaving excessive corresponding nominal (rather than effective) effort on the water.

CONSUMER WELFARE AND PUBLIC BENEFITS OF BIODIVERSITY AND ECOSYSTEM SERVICES

We now formally incorporate nonrivalrous public good benefits from the public goods of biodiversity and ecosystem services. Fish price is now a real (inflation-free) economic price (denoted P_t^*) that can change over time due to changes in relative prices, and cost is a real economic cost (denoted c* and kept constant for simplicity), where * denotes economic values measured by real economic (efficiency) prices when there are market distortions, and U* denotes consumer surplus measured by real economic prices under a general equilibrium inverse derived demand curve for the rivalrous essential input fish. Writing this demand function by $P_t^* = D(Y_t)$, $\partial P_t^* / \partial D(Y_t) < 0$ gives the gross willingness to pay associated with the fish, Y_t, as $U^*(Y_t) = \int_o^\infty D(Y_t)dY$. The objective function in the optimization problem now becomes:

$$PV(U^*, \pi^*) = \int_0^\infty [U^*(Y_t) - C^*[Y_t, B_t, t, -\mu(t, Z)]]e^{-\delta t}dt,$$

where $C^*[Y_t, B_t, r^*, t, -\mu(t, Z)]$ is the real economic cost of harvesting (measured in real economic prices for inputs, r^*).

Now, let $W^*(B_t)$ denote willingness to pay (or accept, depending upon who has the property right and has standing) for separable consumer utility from external benefits due to the public goods of biodiversity and ecosystem services (Bulte, Folkmer, and Heijman 1998; van Kooten and Bulte 2000). The total willingness to pay measured in real economic prices is then $U^*(Y_t) + W^*(B_t) = \int_o^\infty D(Y_t)dY + W(B_t)$. The optimization problem leading to MEY is now written:

$$PV(U^*, W^*, \pi^*) = \int_0^\infty \left[U^*(Y_t) + W^*(B_t) - C^*[Y_t, B_t, t, -\mu(t, Z)]\right]e^{-\delta t}dt.$$

This comprehensive measure of consumer and producer benefits provides a comprehensive measure of MEY consistent with microeconomic theory, thereby accounting for economic benefits from economic rent and employment, informal labor and capital markets in developing countries or depressed regions, indirect effects, market distortions, accumulated and new disembodied and embodied technology, all consumer and producer economic welfare throughout the value chain up to and including consumers accounting for both rivalrous and nonrivalrous inputs and outputs, the common resource stock and public good externalities for biodiversity and ecosystem services, and more comprehensive dynamic Debreu-Farrell economic efficiency rather than simply dynamic scale efficiency.

When including the non-market values, $W(B_t)$ the Golden Rule is expanded by a new term called the marginal public effect, accounts for the non-market public benefits from the resource stock, and modifies the term of Bulte et al. (1998) and van Kooten and Bulte (2000) to account for the effects of changes in technology as well as technical and allocative efficiency and use of real economic prices:

$$\partial W/\partial B_t / \left(P - \frac{C^*}{qB_t e^{(\lambda + M\psi)t - \mu(t,Z)}} \right).$$

Adding this term will lead to a higher economic optimal stock level of B_{MEY}.

TAKING STOCK: MEY VS. MSY

Where does the above discussion leave us in the relationships between MEY and MSY and B_{MEY} and B_{MSY} when accounting for: (1) the appropriate measurement of costs and benefits in estimates of MEY and (2) the need to extend MEY beyond the relationship between the harvest sector and the resource stock externality? A strong case has been made for $B_{MEY} > B_{MSY}$ in many instances (Grafton, Kompas, and Hilborn 2007; Grafton et al. 2012). Christensen (2009) contends that MSY = MEY when accounting for the full benefits in the value chain. Sumaila and Hannesson (2010) state that MEY differs from MSY, even when the net benefits from the full value chain are included.

Throughout our discussion we have implicitly assumed that the fishery regulation is designed so that MEY is a meaningful concept. Schwindt, Vining, and Gloverman (2000) studied Canadian Pacific salmon fishery, which, in practice, was open access, and concluded that the economic welfare was negative. In such cases MEY is zero. The reason for this result is that they included management costs, and, in general, these should be included in the assessment of MEY.

Our first key point is that MEY is not the full economic MEY until all market distortions are accounted for through the judicious use of economic (efficiency) prices. Accounting for market distortions and financial transfers through economic rather than financial prices (observed market prices) allows accounting for "social" benefits (indirect effects), such as employment and persistent excess capacity and foreign exchange earnings. We have emphasized that zero shadow pricing of unemployed labor is, in general, not correct; instead there is a positive shadow wage rate. Such an approach remains inherently second best in that market distortions within the overall economy are taken as given, even though common resource and public externalities are optimized. In a narrow sense, the fishery economy is ostensibly first best.

Second, accounting for consumer benefits and value chain activities, in addition to the harvesting sector, captures the full range of consumer and producer benefits and costs. This approach also makes the numeráire (unit of account) become consumption in the present period, where the consumption of all goods and services is measured by the real income required to purchase them in units of present value, real prices, and domestic currency. Such a numeráire is consistent with standard national and international practices in applied welfare economics analysis and allows MEY and B_{MEY} to provide single quantitative measures of the socially optimum stock, which MSY cannot provide because its numeráire (metric tons of biomass or fish numbers) does not allow incorporating benefits and costs in different units.

Third, social prices, while accounting for equity and economic efficiency, have never been widely estimated and applied. Social prices require an explicit social welfare function, there is considerable debate over their validity, and conventional practice assigns equal welfare weights. Social prices might instead best be thought of within a first-best framework that provides a conceptual guide, rather than used in actual practice, and allows use of a common numeráire that integrates biological, economic, and social issues into a single monetary measure of MEY and B_{MEY}. Efficiency-equity tradeoffs are conventionally handled by other approaches.

Fourth, accounting for accumulated and new technology as well as changes in dynamic scale, allocative, and technical efficiency, but not market distortions other than the common resource externality, means that, in many instances, eventually $B_{MEY} < B_{MSY}$, even when properly measuring and accounting for all economic costs and benefits throughout the value chain. Effective effort (accounting for accumulated and new technology and dynamic Debreu-Farrell economic efficiency) can be expected to be less than nominal effort at either MEY or MSY.

Fifth, non-autonomous bioeconomic models are ideally required. If not estimated, then constant updating of autonomous bioeconomic models as part of adaptive management is necessary as an approximation.

Sixth, accounting for technical and allocative efficiency gives a more comprehensive, accurate measure of MEY beyond the incomplete measure that accounts only for dynamic scale efficiency.

Seventh, MEY, as discussed in the literature, largely ignores nonmarket external benefits from the (impure or pure) public goods of biodiversity and ecosystem services (a market distortion we single out as one of the most important for fisheries going forward). See Kronbak, Squires, and Vestergaard (2014) for a comprehensive discussion. When the public benefits from leaving fish in the water (biodiversity, ecosystem services) are explicitly incorporated into the dynamic model (Bulte, Folmer, and Heijman 1998; van Kooten and Bulte 2000), B_{MEY} increases relative to B_{MSY}, although the extent is unknown and likely varies over time and by fishery (Squires and Vestergaard 2013a,b). Whether or not dynamic B_{MEY}, incorporating all of the above discussion, surpasses B_{MSY} or even reaches the "traditional" B_{MEY} that is often expected to exceed B_{MSY} remains an open, empirical question (Grafton, Kompas, and Hilborn 2007; Grafton et al. 2012).

In sum, until all consumer and producer benefits, market distortions, accumulated and new technology, and economic efficiency are accounted for and properly measured, and most notably, the full external benefits derived from biodiversity conservation and ecosystem based fisheries management are accounted for, whether B_{MEY} exceeds, equals, or falls short of B_{MSY} remains an open question that will undoubtedly vary by fishery. This relationship between B_{MEY} and B_{MSY} is also likely to change and fluctuate over time due to changes in technology, technical efficiency, relative prices, market distortions, fish recruitment, the environment, society's preferences that increasingly value biodiversity and ecosystem services, and other factors. Policies based on no-growth, steady-state equilibrium generate opportunity costs to society that rise over time (Squires and Vestergaard 2013a,b). As stressed by Dichmont et al. (2010), some form of updating and adaptive management is undoubtedly required.

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