Accounting for income and population dynamics in benefit-cost analysis: an application to dam removal

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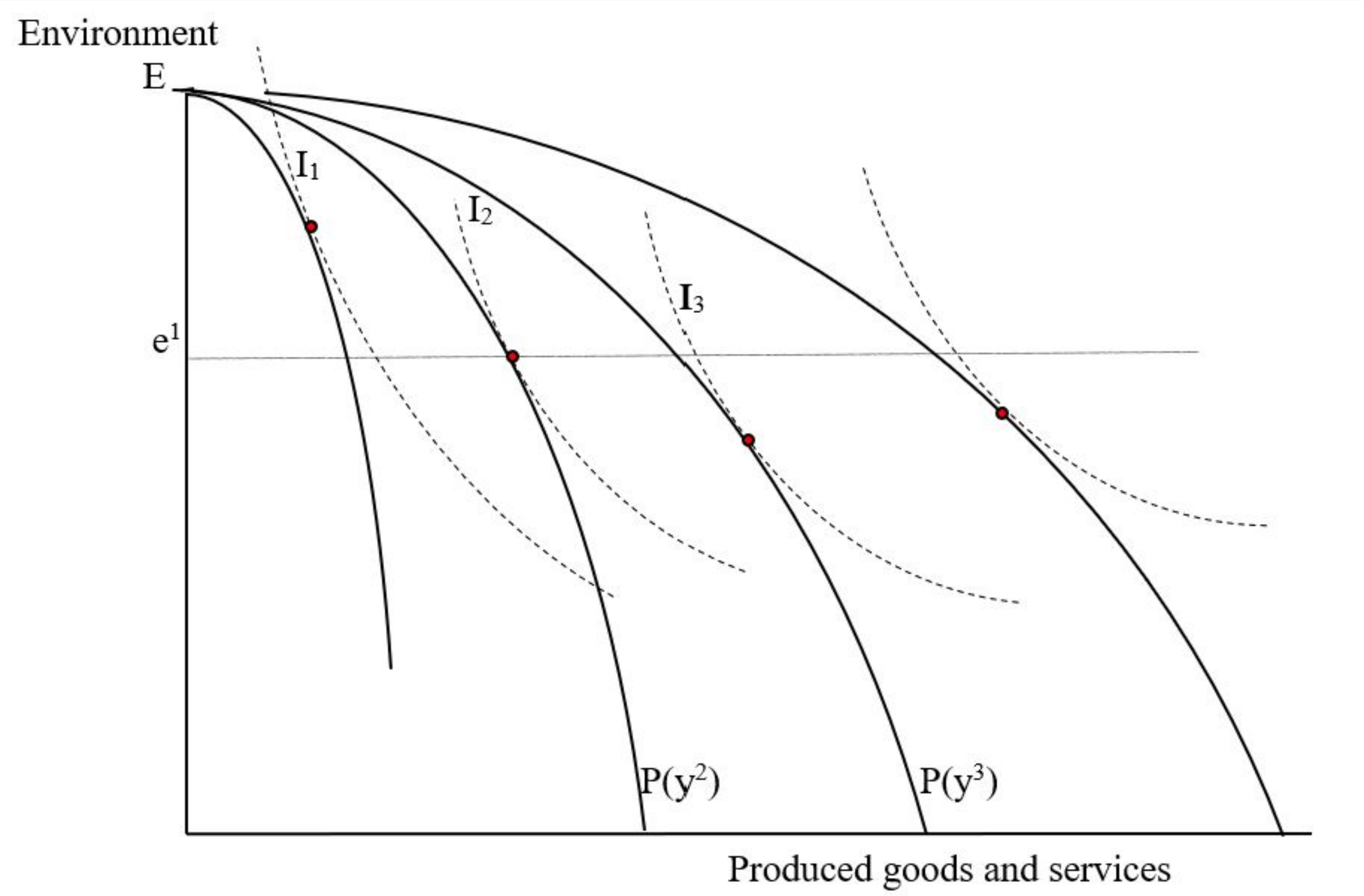
"… "while the supply of fabricated goods and commercial services may be capable of continuous expansion from a given resource base by reason of scientific discovery and mastery of technique, the supply of natural phenomena is virtually inelastic …"

"Accordingly, if we simply take the effect of technological progress over time, considering tastes as constant, the marginal trade-off between manufactured and natural amenities will progressively favor the latter. Natural environments will represent irreplaceable assets of appreciating value with the passage of time (p.783)."

- John Krutilla, Conservation Reconsidered, American Economic Review, 1967.



Environment
E
I_1
I_2
I_3
e^1
$P(y^2)$
$P(y^3)$
Produced goods and services

Renewed interest in this question arose around 2007:

"… we should discount costs but also take into account the increase in the relative price of the ecosystem service endangered"

- Hoel and Sterner. 2007. *Climatic Change.*

"… we show that rising relative prices can have important implications for the efficient level of climate change mitigation."

- Sterner and Persson. 2008. *Review of Environmental Economics and Policy.*

Recent literature has developed a simple rule to estimate these relative price changes

- Drupp and Hänsel. 2021. American Economic Journal: Economic Policy.
- Heckenhahn and Drupp. 2024. Environmental and Resource Economics

(Also Ebert 2003; Weikard and Zhu 2005; Yu and Abler 2010; Baumgärtner et al. 2015; Baumgärtner et al. 2017; Heckenhahn and Drupp 2024.)

Relative price change estimation with rising incomes

In a model with CES preferences, one can derive a straightforward expression for the relative price change (RPC) over time, as a function of the elasticity of substitution, σ, between c and e, the growth rate for market goods (reflecting income growth), g_{C_t} , and the growth in ecosystem services, g_{E_t} :

$$RPC_t = \frac{1}{\sigma}\left(g_{C_t} - g_{E_t}\right)$$

In this setting, σ is directly and inversely related to the income elasticity of WTP for nonmarket ecosystem services, ϵ_W, such that $\epsilon_W = 1/\sigma$.

$$\boxed{RPC_t = \epsilon_W (g_{C_t} - g_{E_t})}$$

There are numerous estimates of the income elasticity of WTP

- Across various ecosystem service types, provisioning, regulatory, cultural services, (Drupp et al. 2023), these elasticities of WTP have been estimated regionally and globally (Baumgärtner et al. 2015), include meta-analyses suggesting a range of point estimates between 0.4 to 0.8 (Drupp et al., 2024).

POLICY FORUM

ENVIRONMENTAL ECONOMICS

Accounting for the increasing benefits from scarce ecosystems

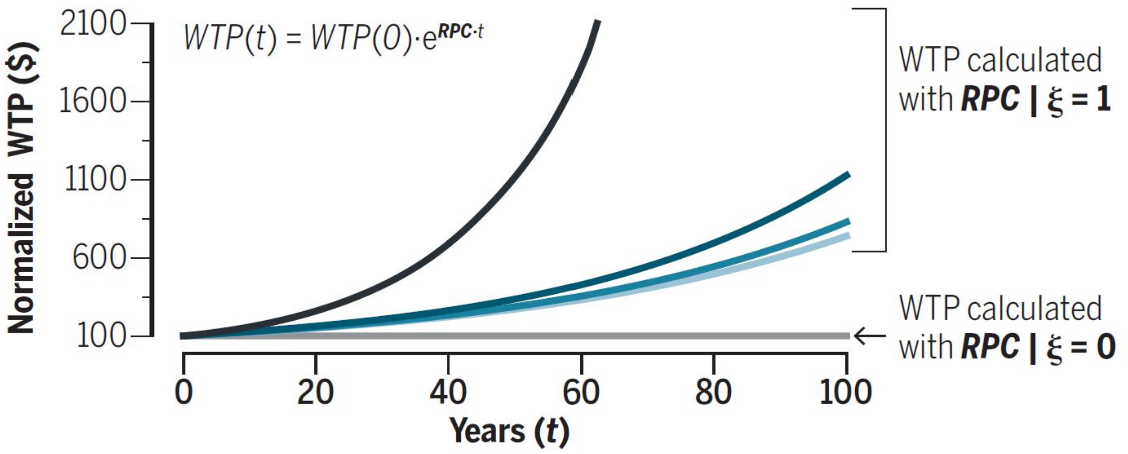
As people get richer, and ecosystem services scarcer, policy-relevant estimates of ecosystem value must rise

By M. A. Drupp[1], M. C. Hänsel[2,3], E. P. Fenichel[4], M. Freeman[5], C. Gollier[6], B. Groom[7,8], G. M. Heal[9], P. H. Howard[10], A. Millner[11], F. C. Moore[12], F. Nesje[13], M. F. Quaas[2,14], S. Smulders[15], T. Sterner[16], C. Traeger[17], F. Venmans[8]

Our proposal will correct a substantial downward bias in currently used estimates of future ecosystem service values. This will help governments to reflect the importance of ecosystems more accurately in benefit-cost analyses and policy decisions they inform.

Evolution of willingness to pay

WTPs increase over time when applying the RPC adjustments using the new default ($\xi = 1$) from panel 2. Future WTPs for stagnating ecosystem services would rise in proportion with real income. For declining ecosystem services, future WTPs would rise faster.



Population growth has parallel implications for future ecosystem service values

- For rival ecosystem services, population growth reduces per capita availability (negative g_E)
- For nonrival environmental goods, population growth increases the aggregate or total WTP
- Our RPC expressions need to account for both dynamics

RVC (relative value change) with population growth

For population *P* and its growth rate G_P in period *t*

<u>For rival ecosystem services</u>

- One component varies inversely with G_P

$$g_P^R = \frac{-G_p}{\left(1+G_p\right)}$$

- Second component reflects growth in ecosystem services g_Q^R

- Combined per capita growth in R will be: $g_E^R = g_Q^R + g_P^R$

For nonrival ecosystem services

The absolute scarcity of the ecosystem service may be unchanged with population growth, but its value will rise with the number of beneficiaries

In CV studies, the mean or median WTP, $\overline{v}$, is used to compute the aggregate environmental value $V^{NR} = \overline{v}P$

With an initial aggregate value V_0^{NR} and population growth, G_{P_t}, the predicted value

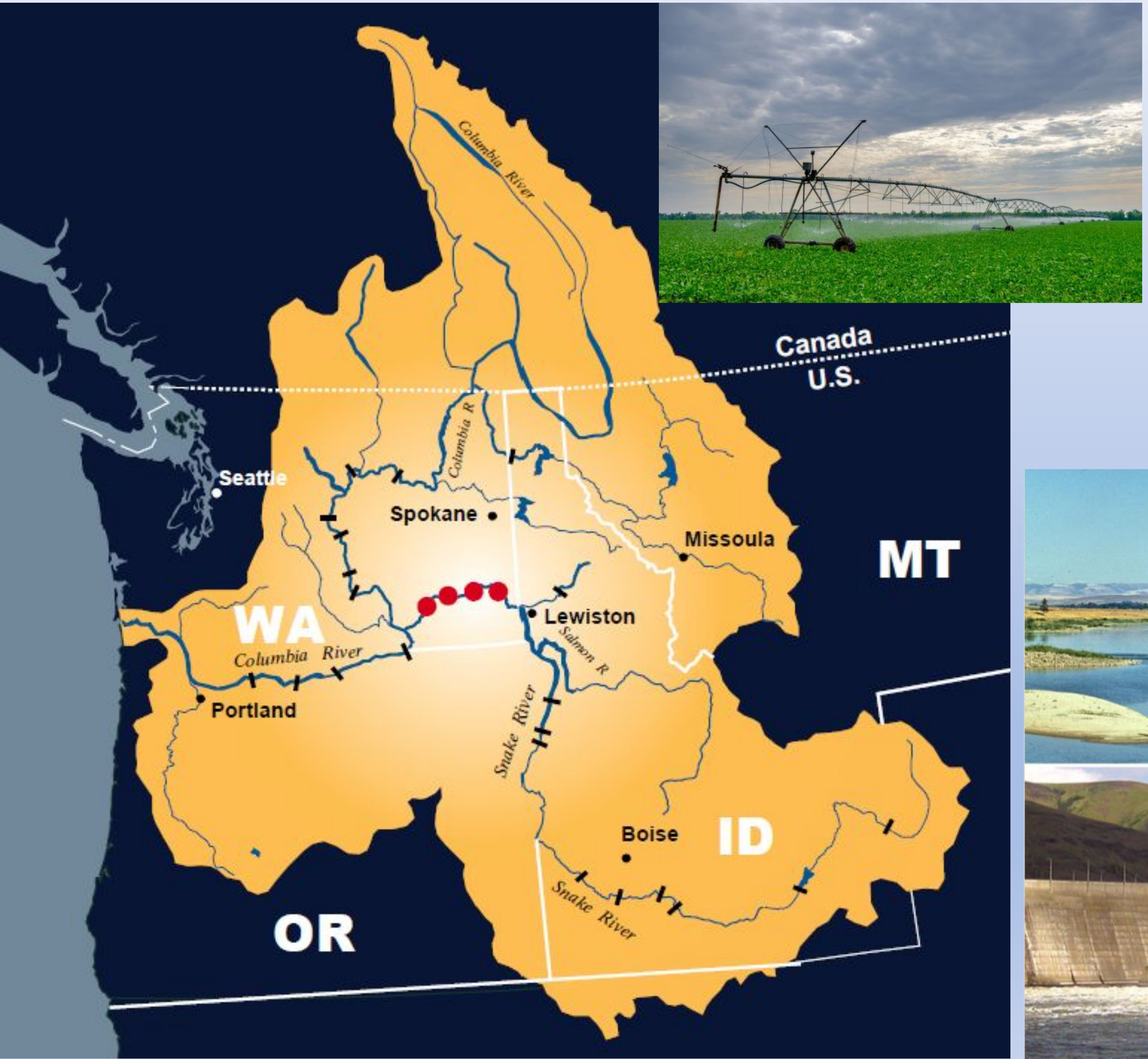
in period t can be written as $V_t^{NR} = \left(1 + G_{P_t}\right)V_0^{NR}$

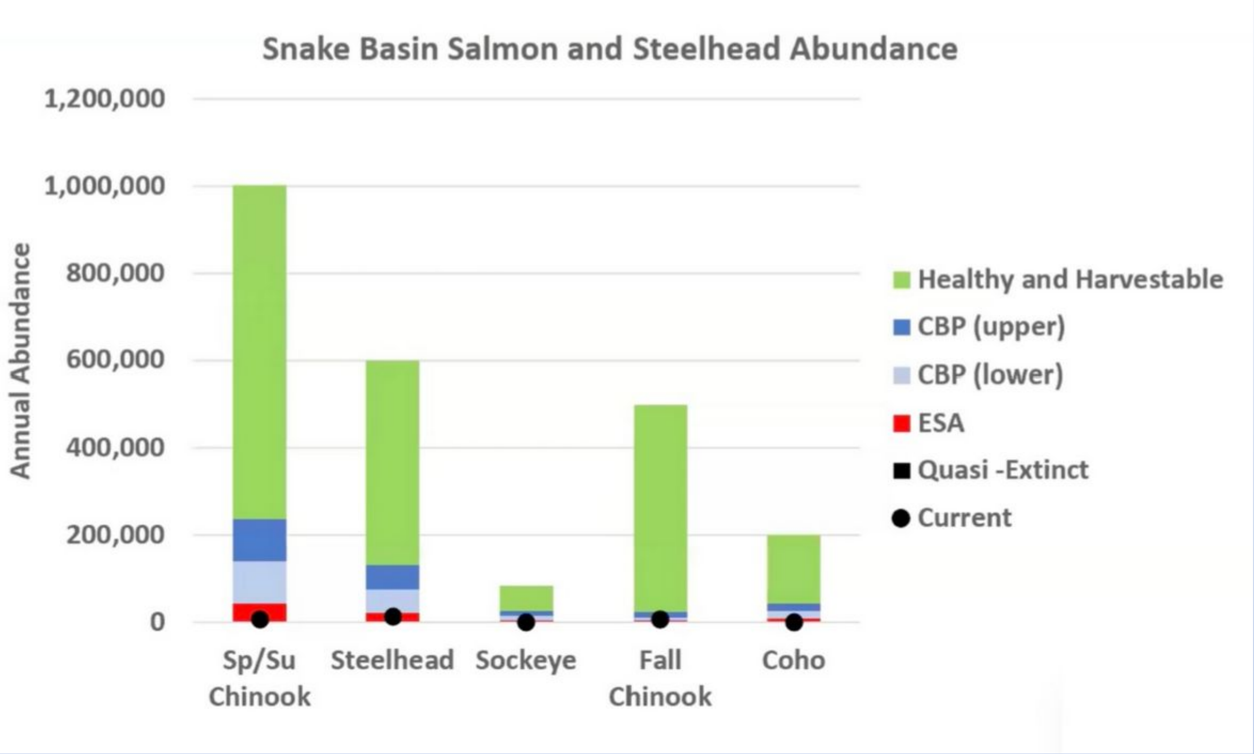
$$V_t^{NR} = \left(1 + RPC_t^{NR}\right)\left(1 + G_{p_t}\right)V_0^{NR} \boxed{= \left[1 + \epsilon_W^{NR}\left(g_{C_t} - g_{E_t}^{NR}\right)\right]\left(1 + G_{p_t}\right)V_0^{NR}}$$

Supposition: policymakers need concrete evidence of these biases to decide to address them

- How big or small are these biases?
- How do they interact when both dynamics are present?
- Real-world applications and illustrations are needed

Benefit-cost analysis for breaching four lower Snake River dams





US Army Corps of Engineers Feasibility Report/ Environmental Impact Statement (with BPA, EPA, USBR)
- published in 2002
- most data and analysis ~1998
- 3,000+ pages

Alternative 1. No major changes

Alternative 2. Maximize transport of juvenile salmon

Alternative 3*. Major system improvements (selected)

Alternative 4. Breaching of four lower Snake River dams

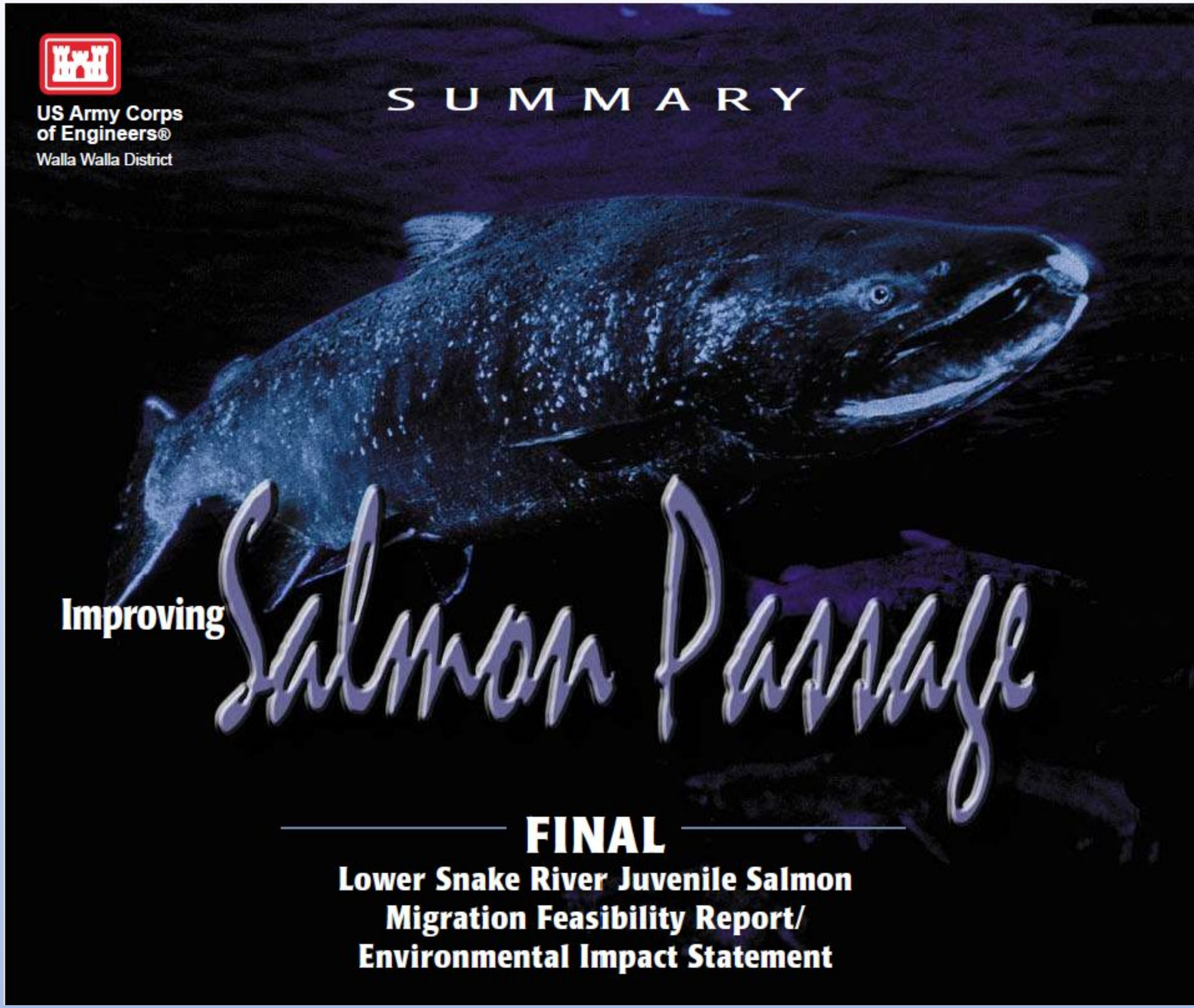


Table 1. Benefit-cost analysis for breaching lower Snake River dams: summary based on 2002 USACE Feasibility Study/Environmental Impact Statement

Costs	Present value ($2022M)	Annualized ($2022M)
Implementation cost	-1,178	-81.1
Power (reduced power generation)	-6,543	-450.4
Transportation (curtailed river shipping)	-913	-62.8
Water supply (less access for irrigation)	-372	-25.6
Total cost	-9,006	-620.0
Benefits		
Avoided costs (dam maintenance, etc.)	810	55.8
Recreation (on newly free flowing river)	1,720	118.4
Commercial fishing (restored fish populations)	36	2.5
Passive use (restored native fish pop., free flowing river)	5,048	347.5
Total benefit	7,614	524.2
Net benefit	-1,392	-95.8

Notes: Values reflect changes from the "no action" alternative using 1998 base year and prices; timeframe is 100-years discounted at 6.875%.

Table 2. Comparing Snake River dam breaching benefit cost analyses under alternative assumptions for relative price changes: original 1998 base year, time frame and discount rate ($2022M)

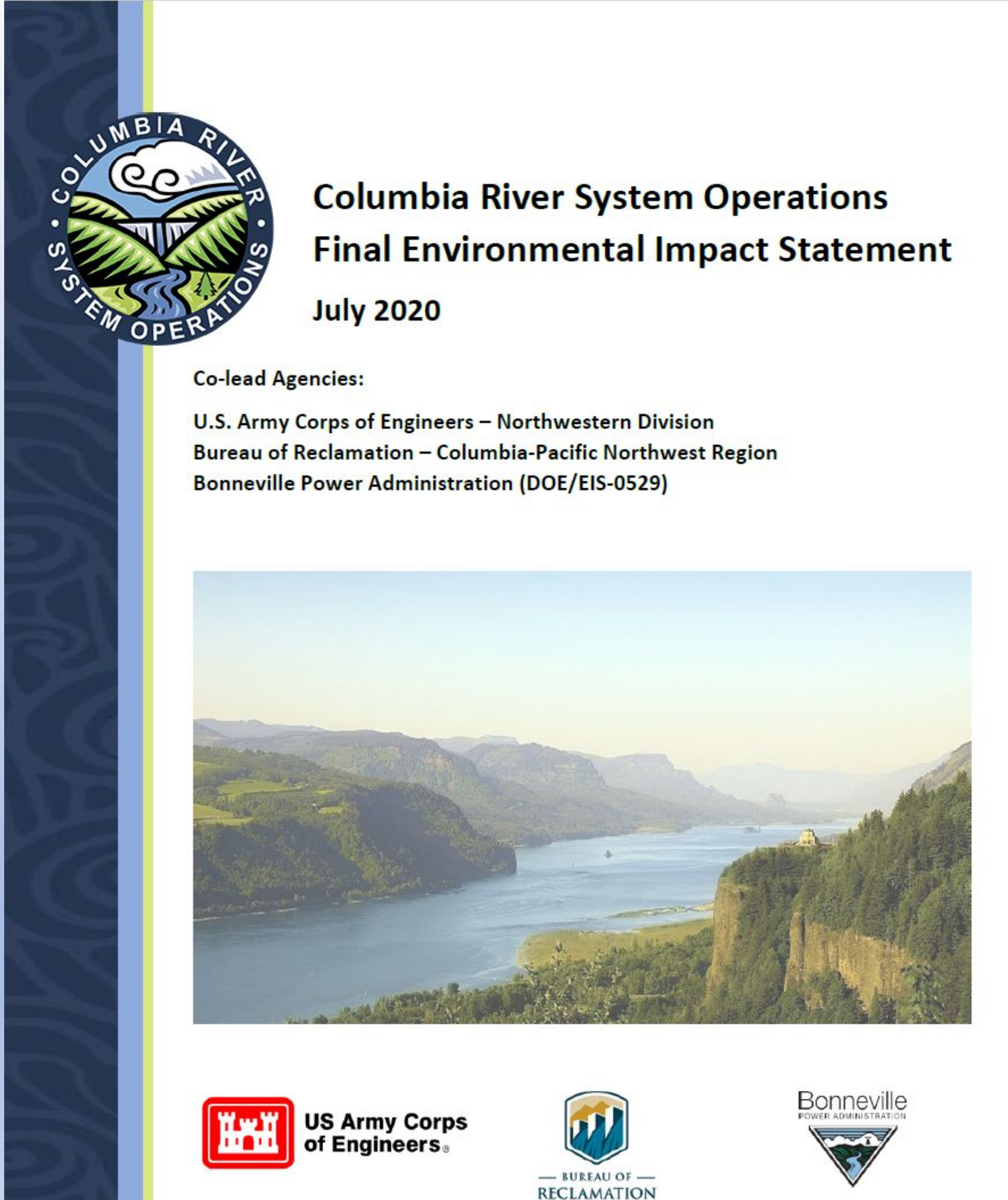
Discount rate 6.785%, 100 year horizon	NPV	Annualized net benefits	PV of benefits	Change in PV of benefits
Original BCA (USACE 2002) (see Table 1)	-1,392	-96	7,614	--
Including income-related relative price changes (recreation assumed to be rival)	1,465	101	10,471	2,857
Including income- and population-related changes (recreation assumed to be rival)	4,923	339	13,929	6,315
Including income- and population-related changes (recreation assumed to be non-rival)	5,345	368	14,351	6,737

Notes: Values reflect changes from the "no action" alternative using 1998 base year and prices. The present value of cost is $9,006 for all model versions.

2020 Columbia River System Operations: Final Environmental Impact Statement

- published in 2020
  - 3,000+ pages

- Ended up used a semi-quantitative scoring approach, not full BCA



COLUMBIA RIVER SYSTEM OPERATIONS

Columbia River System Operations
Final Environmental Impact Statement

July 2020

Co-lead Agencies:

U.S. Army Corps of Engineers – Northwestern Division
Bureau of Reclamation – Columbia-Pacific Northwest Region
Bonneville Power Administration (DOE/EIS-0529)

US Army Corps of Engineers®

BUREAU OF RECLAMATION

Bonneville POWER ADMINISTRATION

Original USACE BCA compared to modified alternatives

	Base year,	Time horizon	discount rate
• Original 1998 BCA	1998	100	6.785%
• Income RPC	1998	100	6.785
• Income & pop RPC	1998	100	6.785
• No RPC adjustment	2023	100	6.785
• Income RPC	2023	100	6.785
• Income & pop RPC	2023	100	6.785
• No RPC adjustment	2023	50	2.0*
• Income RPC	2023	50	2.0
• Income & pop RPC	2023	50	2.0

* See Howard, Peter H., Max Sarinsky, Michael Bauer, Caroline Cecot, Maureen Cropper, Moritz Drupp, Mark Freeman, et al. 2023. "US Benefit-Cost Analysis Requires Revision." *Science*.

Table 3. Comparison of BCAs for breaching lower Snake River dams: adjustments for income and population effects on relative values (2023 base year; millions of $2022)

Discount rate 6.785 % (100 years) [a]	NPV	Annualized net benefit	Benefits (PV)	Change in benefits
BCA updated to 2023	4,535	312	13,541	--
BCA adjusted for income changes (recreation assumed to be rival)	8,932	615	17,938	4,397
BCA adjusted for income and population changes (recreation assumed to be rival)	10,984	756	19,990	6,448
BCA adjusted for income and population changes (recreation assumed to be non-rival)	12,475	859	21,481	7,939

Notes: Values reflect changes from the "no action" alternative using 2023 base year and prices.

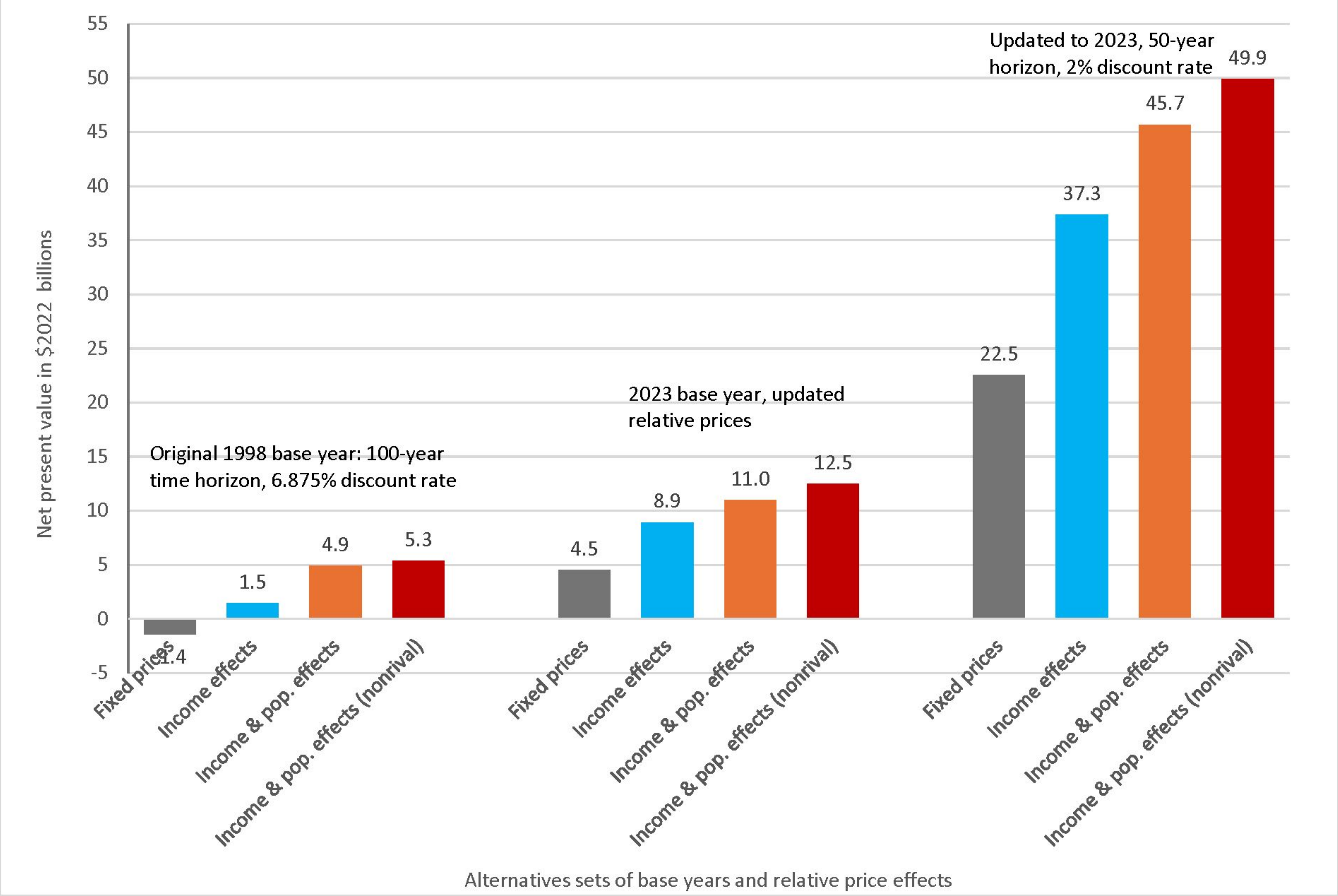
a. The present value of costs is $9B in each model.

Table 4. Comparison of BCAs for breaching lower Snake River dams: adjustments for income and population effects on relative values (2023 base year; millions of $2022)

Discount rate 2% (50 years)[a]	NPV	Annualized net benefit	Benefits (PV)	Change in benefits
BCA updated to 2023	22,547	732	41,155	--
BCA adjusted for income changes (recreation assumed to be rival)	37,344	1,203	55,952	14,798
BCA adjusted for income and population changes (recreation assumed to be rival)	45,681	1,468	64,289	23,134
BCA adjusted for income and population changes (recreation assumed to be non-rival)	49,894	1,602	68,502	27,347

Notes: Values reflect changes from the "no action" alternative using 1998 base year and prices and values.

a. The present value of costs are $18.6B in each model.


Net present value in $2022 billions
55
50
45
40
35
30
25
20
15
10
5
0
-5
Original 1998 base year: 100-year time horizon, 6.875% discount rate
2023 base year, updated relative prices
Updated to 2023, 50-year horizon, 2% discount rate
-1.4
1.5
4.9
5.3
4.5
8.9
11.0
12.5
22.5
37.3
45.7
49.9
Fixed prices
Income effects
Income & pop. effects
Income & pop. effects (nonrival)
Fixed prices
Income effects
Income & pop. effects
Income & pop. effects (nonrival)
Fixed prices
Income effects
Income & pop. effects
Income & pop. effects (nonrival)
Alternatives sets of base years and relative price effects

Questions?