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Research article

Substituting freshwater: Can ocean desalination and water recycling capacities substitute for groundwater depletion in California?

Pierre Badiuzzaman*, Eoin McLaughlin, Darren McCauley

Department of Geography and Sustainable Development, University of St. Andrews, Irvine Building, St Andrews, KY16 9AL, Scotland, United Kingdom

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ABSTRACT

While the sustainability of resource depletion is a longstanding environmental concern, wider attention has recently been given to growing water scarcity and groundwater depletion. This study seeks to test the substitutability assumption embedded in weak sustainability indicators using a case study of Californian water supply. The volume of groundwater depletion is used as a proxy for unsustainable water consumption, and defined by synthesising existing research estimates into low, medium and high depletion baselines. These are compared against projected water supply increases from ocean desalination and water recycling by 2035, to determine whether new, drought-proof water sources can substitute for currently unsustainable groundwater consumption. Results show that the maximum projected supply of new water, 2.47 million acre-feet per year (MAF/yr), is sufficient to meet low depletion estimates of 2.02 MAF/yr, but fails to come near the high depletion estimate of 3.44 MAF/yr. This does not necessarily indicate physical limitations of substitutability, but more so socio-economic limitations influenced by high comparative costs. By including capacities in demand-substitutability via urban water conservation, maximum predicted capacities reach 5.57 MAF/yr, indicating wide room for substitution. Based on these results, investment in social and institutional capital is an important factor to enhance demand-side substitutability of water and other natural resources, which has been somewhat neglected by the literature on the substitutability of natural resources.

1. Introduction

Major international development agencies have sought to expand the current conceptualisation of national accounts to include wider measures of wealth that are important for monitoring sustainability prospects (World Bank, 2011; UNU and UNEP, 2012, 2014). Both the World Bank and UN agree, that the environment i.e. natural capital has been particularly neglected and needs to be included in total wealth accounts of nations (*Ibid.*).[1] Within their natural capital stocks, however, neither accounts for water resources although they constitute an “essential factor” in most economic activity (Perry, 2012, p.216; Gleick, 2001). The availability of freshwater forms an irreplaceable foundation for human life, ecosystem health and civilizational prosperity. Predicted increase of regional water scarcity is a key challenge of the 21st century, likely to impose adverse effects on agricultural production, food security and a variety of economic activities (Savenije, 2002; Postel, 2000; Cooley et al., 2014; Seckler et al., 1999; IPCC, 2014; DWR, 2008; Rijsberman, 2006; Famiglietti et al., 2011).

In the context of increasing scarcity, the question of substitutability, i.e. the ease with which to replace one resource with another, figures prominently in the economic debate of sustainability, which will be discussed in the theoretical context section (Neumayer, 2013; Ekins, 2002). Empirical work on the substitutability of water is very scarce despite its policy relevance. Measuring the economic value of water is a major challenge, making it seemingly impossible to ‘test’ its substitutability quantitatively (Drupps, 2015; Atkinson et al., 2012). Therefore, this article seeks to shed new light on the matter by using a case study to assess feasible water substitution capacities within the State of California.

California presents an interesting and socially relevant case because it provides common water scarcity challenges faced by arid regions and critical conditions to analyse substitutability, given availability of data and implementation of new supply technologies (Yin, 2014; IPCC, 2014; UN, 2012; Cooley et al., 2014; Seckler et al.,

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* Corresponding author. Present address: 5a Mount Street, Taunton, TA1 3QB, United Kingdom.

E-mail address: pierre_badiuzzaman@outlook.com (P. Badiuzzaman).

[1] The UN Inclusive Wealth Report additionally highlights the overarching importance of health for total wealth (UNU and UNEP, 2012, 2014).

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1999). Ongoing groundwater overdraft and adverse, climate change induced effects on water availability will likely exercise severe pressure on the State's water resources and its ability to sustain tremendous population growth, which is projected to rise from 38.4 to 51 million by 2050 (DWR, 2014c, p.4; Famiglietti et al., 2011). With its main water resources already exploited to their ecological and physical limits, California seeks "state-wide water supply reliability and sustainability" (DWR, 2014b, p.9–5; Gleick and Palaniappan, 2010). Among other measures, water suppliers are legally mandated to evaluate desalination and recycling as options to meet the goals of their water resource management plans (*Ibid*; Cooley and Ajami, 2014; USBR, 2012).

Responding to the question, whether we can "supply our way out of scarcity?", this article analyses new water supply capacities from ocean desalination and water recycling to determine whether current water consumption can be sustained (Zetland, 2014a, p.11). This research article seeks to answer whether predicted capacities from those two sources can provide sufficient quantities of freshwater by 2035 to substitute for unsustainable groundwater depletion in California?

To provide a theoretical and analytical framework for the case study, section 2 outlines the discussion on the substitutability of natural resources and water. Methodological assumptions are stated in section 3. Section 4 contextualises the case study, compares Californian groundwater depletion with water supply capacities of ocean desalination and water recycling, before introducing the impact of demand-side options and presenting socio-economic cost considerations. Finally, the discussion (5) assesses the results and highlights the importance of social/institutional capital for water substitutability.

2. Theoretical context: water substitutability

2.1. The substitutability assumption and limits to substitution

Economic thinking about sustainability focuses on accumulating and managing total wealth efficiently to ensure optimal consumption and welfare into the future (Barbier, 2011; Hanley et al., 2015; Arrow et al., 2012).[2] Using total wealth as an indicator for sustainability implies optimal resource allocation and unlimited substitutability in monetary terms between different forms of capital. These form underlying assumptions within the economic model of weak sustainability (Pearce et al., 1989; Hanley et al., 2015; Hamilton and Hepburn, 2014, Hartwick, 1977). The adequacy of these assumptions fundamentally depends on adequate monetary valuation or pricing of a good to indicate scarcity, the rate of technical progress and the possibilities of substitution between forms of capital (Lecomber, 1975; Neumayer, 2013; Hediger, 2006; Hanley et al., 2013).

The relevance of the substitutability of natural capital was highlighted in the debate on Climate Change mitigation. It showed that different views often arise from economists focusing on substitution at the margin (in monetary terms) while most natural scientists assess ultimate physical limitations (Fenichel and Zhao, 2014; Heal, 2009; Drupps, 2015; IPCC, 2014).[3] Economically, substitutability can be measured as the elasticity of substitution, which "captures the ease with which a decline in one input can be compensated by an increase in another, while holding output constant" (Markandya and Pedroso-Galinato, 2007, p.298). Empirical studies of elasticities of substitution between K_P and K_N are scarce and build on "non-falsifiable beliefs" about technical progress and future substitution possibilities (Neumayer, 2013, p.192f.; Ibid; Atkinson et al., 2012; Dietz and Maddison, 2009; Drupps, 2015). In theory, proponents of weak sustainability (WS) assume that economic scarcity leads to price increases, which result in 4 different effects/propositions that support the substitutability of various capital forms, as outlined by Neumayer (2013) (See Appendix A.1 for detailed description):

1. Scarcity makes substitutability with another resource economically viable due to its comparatively lower cost.
2. Prices signal economic scarcity and drive dynamic markets to adapt towards efficiency under new scarcity conditions.
3. Natural resources are substituted with produced capital if the elasticity of substitution is greater or equal to 1.
4. Technical progress affects substitutability through efficiency gains and via cheaper production techniques, which increase the economically available stock of less profitable resources.

This framework of arguments does not mention institutional or social capital, despite their great importance to overall wealth and their ability to improve factor productivity. Institutional and social capital can support intensive and structurally driven growth without further increasing natural resource use, thus potentially enhancing the substitutability of K_N (Hamilton and Hepburn, 2014; Hamilton and Liu, 2014; North, 1990). The absence in the analysed literature is surprising, considering that intangible capital, which is assumed to be mostly social and institutional capital, accounted for 29% of comprehensive wealth in the USA in 2005 (World Bank, 2011). The intangible character makes quantification difficult, but does not justify complete omission (Hamilton and Liu, 2014; Putnam, 2001). While institutional capital includes the capacity and effectiveness of legislative rules and institutions; social capital refers to local cooperation, trust, networks, and societal norms (Bottrill and Pressey, 2012; Hearne, 2007; North, 1990; Lee et al., 2011).

2.2. Water and substitutability

2.2.1. Water characteristics and usage types

Hydrologically, water has both renewable and non-renewable resource characteristics. The main renewable water components are river runoff and the groundwater inflow into rivers. Their flow rate determines the limits of water provision and indicates scarcity (Shiklomanov 2000; Perry, 2012). Abstracting the total amount of water replenished in a watershed each year is termed 'peak renewable water' and severely damaging to ecosystems (Gleeson et al., 2012; Wilson and Carpenter, 1999). According to Gleick and Palaniappan (2010), 'peak ecological water' would be the maximum abstraction which avoids uneconomic ecosystem damages.

Non-renewable resources such as lakes, reservoirs, groundwater aquifers or mountain snowpack are physically limited by their stock, which changes depending on in- and outflows. With recharge rates of up to 1500 years, some of these are "effectively non-renewable" (Gleeson et al., 2010, p.379; *Ibid*.).[4] The point of maximum abstraction in spite of greater costs is termed 'Peak non-renewable water' (Gleick and Palaniappan, 2010).

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[2] Total wealth is the sum of different capital stocks such as produced capital (K_P); natural capital (K_N); human capital (K_H); social capital and institutional capital (K_S) and intangible capital (Hamilton and Hepburn, 2014).

[3] Substitutability at the margin means analysing substitutability for each incremental unit.

[4] Fossil water is non-renewable groundwater that "entered the aquifer as recharge in past geologic periods" and which is not replenished through annual runoff (Pereira et al., 2009, p.136).