Review of "Endogenous technological and population change under increasing water scarcity."

The authors develop and present an endogenous growth model of a closed society making consumption decisions in the presence of an exogenously declining resource. The authors identify declining consumption per-capita as a "credible" predictor of eventual population decline, even in the presence of increasing production and technological innovation. Mathematically, the model is developed correctly, given the authors assumptions, and is well motivated. I had two major concerns with how widely these results can be applied, however.

In the model presented in this paper, because of the formulation of the production function, unless technological innovation experiences unrealistic growth, the exogenous depletion of the water resource necessarily drives production to zero. As a result, this is fairly trivial, and, I would suggest, unrealistic. The authors model the economy that uses a nonrenewable water resource in its production of consumer goods. The nonrenewable resource is depleted at an exogenous rate, and has no possible substitute in production. While the substitutability of water, by its nature, is necessarily low, farmers, municipalities and industrial users of water substitute between water resources or sources. So, if one source of water declines, users can substitute water from another source, usually at a higher cost. There are situations in which all sources of water decline or in which users only have access to a single source of water, but in the vast majority of those cases, the water available does not decrease to zero. Even in the widely research case of the Ogallala aquifer on the North American High Plains, in which the aquifer faces total depletion in many areas, farmers can rely on a much smaller and more uncertain, but decidedly nonzero, quantity of available rainwater. Also, in this case, users of the water are responsible for its decline, rather than the decline occurring exogenously. The hydro-climatic change the authors hope to model should not, in all but the most extreme cases, drive the water resource to zero availability. Given this, I would be interested in seeing model runs in which *X* declines to a non-zero value – I would expect that, for some parameter set, the same dynamics in population, consumption, production etc. would occur.

My second concern is in the feedback between technological innovation and the availability of water. The authors argue that technological innovation is likely to be higher when water is more scarce (lines 10-19, page 13516), however, I don't think that's the case, given the model as presented in the paper. Technological change is

$$\frac{v_{t+1} - v_t}{v_t} = \gamma S_t \left(\theta \delta w_t^U + \frac{Q_t}{S_t} \right)$$

Substituting $\delta = {}^{U_t}/_{S_t}$, $w_t^U = \beta v_t X_t^\alpha U_t^{\beta-1} E_t^{1-\alpha-\beta}$, and $Q_t = \alpha f(X_t, U_t, E_t; v_t)$ I get

$$\frac{v_{t+1} - v_t}{v_t} = \gamma \left(\theta U_t \beta v_t X_t^\alpha U_t^{\beta-1} E_t^{1-\alpha-\beta} + \alpha v_t X_t^\alpha U_t^\beta E_t^{1-\alpha-\beta} \right),$$

so,

$$\frac{\partial\left(\frac{v_{t+1} - v_t}{v_t}\right)}{\partial X_t} > 0.$$

This implies that technological change is greatest, in absolute terms, when the resource is at its largest. This is borne out in the simulation, as well, as fig 1A shows that the largest increases in technology level occur at earlier periods. In my opinion, this misses a fundamental feedback in an endogenous growth model of a nonrenewable natural resource. Accepting this relationship as I've derived it here would ignore the large and established literature in induced technological change (e.g. Ruttan, 1971; and Hayami and Ruttan, 1970) which indicates that technology to address resource use isn't developed until the scarcity of the resource rises. I would like to see this relationship, between technological change and resource scarcity.

References:

Hayami, Y. and V.W. Ruttan, "Factor Prices and Technical Change in Agricultural Development: The United States and Japan, 1880-1960." *Journal of Political Economy*, 78(1970):1115-1141.

Ruttan, V.W., "Technology and the Environment." *American Journal of Agricultural Economics*, 53(1971):707-717.