Welfare effects of resource shocks and hyperbolic behavior of the Harberger model

Travis Warziniack*
USFS Rocky Mountain Research Station
2150-A Centre Avenue Fort Collins, CO 80526
twwarziniack@fs.fed.us
phone: +1 (970) 295-5960

Abstract

This paper uses a familiar version of the Harberger model to examine the burden of shocks to the supply of a natural resource, such as may occur due to natural variations in resource variability (e.g., drought) and policies that restrict use of environmental inputs. I show that for this class of models, an asymptote exists around which changes in returns to factors are large and across which the direction of incidence changes. Policies that initially benefit labor can end up harming labor following minor changes in the economy, such as changes in factor shares that are known to vary over time. This paper is the first to address this asymptote, though it affects the results of many familiar models. The model is used to explain agricultural development in dry regions, with a numerical example for water reductions in the Kingdom of Jordan. Water reductions in many developing countries have led to more capital-intensive farming practices. The long run benefits of these investments are mixed. They insulate all factors of production from impacts due to water shortages, but may also discourage capital investment in growth-oriented industries.

Keywords: water, incidence, agriculture, Jordan, irrigation, ecosystem services, Harberger
JEL Codes: O13, O15, Q15, Q25, Q56

*This project began while the author was a professor at University of Heidelberg. Colleagues in Heidelberg gave invaluable feedback throughout.

1 Introduction

This paper came out of a development project in the Kingdom of Jordan. The original intent was to use the well-worn Harberger tax incidence model (Harberger, 1962) to examine distributional effects of water shortages and agricultural reform in Jordan, largely following Fullerton and Heutel (2007). The Harberger model is one of the simplest general equilibrium models out there, and as such, has been used to explain the effects of a wide array of public policies. According to Google Scholar, the 1962 Harberger paper has been cited 875 times (accessed August 23, 2011).

The main theoretical contribution of this paper is the discovery of an asymptote that exists in the two-good three-factor Harberger model around which changes in returns to factors are large and across which the direction of incidence changes - heading to either positive or negative infinity with small perturbations in parameter values. Despite the popularity of the Harberger model, this asymptotic property has not been mentioned. Early models were not plagued by the asymptote. It was only as the model was extended to include at least two goods and three factors, popular in environmental applications, that the issue appears.

The model is developed with changes to Jordan's water policy in mind, and is used to explain structural changes in the agricultural sector that mirror structural changes in Jordan's social makeup. Jordan's annual water budget is about 140 cubic meters of water per capita, indicating 'absolute water scarcity' (Khaleq, 2008). The World Bank considers levels below 1000 cubic meters per capita likely to impede economic growth and human development (Falkenmark et al., 1998). Per capita water continues to fall as Jordan experiences one of the world's highest rates of natural population growth and large periodic influxes of refugees (Daoud, 2000). Eighty percent of Jordan's land area receives less than 100 mm per year of precipitation, and evaporation rates range throughout the country from 5 to 80 times the average annual amount of rainfall. Only 3 percent of the land area receives enough rain to grow wheat without the use of irrigation. Jordan's Ministry of Water calculated that annual water demand exceeded its annual water supply of renewable freshwater by 40 percent in 2007.

Shallow wells have mostly dried or become too salty for agricultural use. The need for deep wells and irrigation has caused a shift to more capital-intensive farming practices, leading to the decline of small-holder farming by owners that could not afford to invest in the required equipment. Large corporate farms appeared, and agriculture is now the business of wealthy families. The long run benefits of these investments are mixed. They insulate all factors of production from impacts due to water shortages, but may also discourage capital investment in growth-oriented industries.

According to the 2010 Environmental Performance Index, 17 percent (27 out of 163) of countries studied are overusing their supply of renewable freshwater. Water shortages and quality degradation affect human health (Esrey et al., 1991; Fewtrell et al., 2005; Prüss-Üstün, 2008), slow economic growth (Barbier, 2004), lower levels and quality of groundwater (Wada et al., 2010), and cause the loss of ecosystem services and biodiversity (Chisholm, 2010). More efficient allocation and water markets have received much of the policy attention (e.g., Seung et al. (2000); Rosegrant and Binswanger (1994); Seagraves and Easter (1983)), but absolute reduction of water use will eventually be needed.

The structure of the paper is as follows: Section two presents a basic two-good three-factor Harberger model for studying welfare changes from adjustments in the supply of an environmental input. Section three presents analytical results and discusses the asymptote inherent in these models. Section four applies the model to drought and agricultural policies in Jordan and contains additional discussion based on the numerical results. Section five concludes.

2 Analytical Model

Since its inception in 1962, the Harberger model has become the workhorse for analyzing distributional effects of policy. Mieszkowski (1972) extended the model to three factor inputs, which allowed for complements and substitutes in production and paved the way for use in models with an environmental input. In three-factor models, it is the relative substitutability of factors, rather than their absolute levels of substitutability or complementarity, that determine the incidence of policies. While extending the model to a third input, Mieszkowski reduced the model to consider production of only a single good, presumably to maintain simplicity. Fullerton and Heutel (2007) extended the model to two goods and three factors, which provided a richer framework for general equilibrium analysis of environmental policies, but also opened the model to asymptotic behavior.[1]

This paper follows Fullerton and Heutel's work, but simplifies the model to one of a small open economy in the goods market, rather than a closed economy with a representative consumer. This approach, in which terms of trade are assumed fixed, was also used in Mieszkowski (1966). Open economy models have several advantages over their closed economy counterparts. Unless one is interested in

[1]Fullerton and Heutel (2007) is similar to Fullerton and Heutel (2010), which considers quantity restrictions.

direction of trade flows or consumer substitutions, analysis can be limited to the production-side of the economy. Open models retain most other results while allowing for a cleaner solution. Open economy models are also more common in the development literature (e.g., Shoven and Whalley (1984); Copeland and Taylor (2003)), to which this application belongs. The main difference between approaches is that, in closed economy models quantity restrictions cause a good's price to rise above marginal cost, creating rents that affect distribution of welfare (Fullerton and Metcalf, 2001). In a small open economy, prices are fixed by terms of trade, and quantity restrictions allow firms to operate at lower marginal costs. Rents from quotas may either go to the firm or to the government. The model is as follows:

Two goods X and Y are produced by representative firms in competitive industries. Let i index firms. Production of each good uses capital K_i and labor L_i that are mobile between sectors and earn P_K and P_L in factor markets. Production of X also uses an environmental input Q. Use of the environmental input is capped at $\bar{Q}$, either by government policy or natural limits of the resource. Water use, for example, is capped by government set quotas, precipitation, and reservoir capacity. Caps exist for use of public land, discharge of pollutants, taking of wildlife, etc. The government charges a per unit fee τ to use the resource. Terms of trade fix goods prices at world prices P_X and P_Y.

Production decisions are made by cost minimizing firms using constant returns to scale production functions, $X = X(K_X, L_X, Q)$ and $Y = Y(K_Y, L_Y)$. Let c_X be the cost function for firm X. Firm X's cost minimization problem is

$$c_X(P_K, P_L, \tau, X) = \min_{K_X, L_X, Q} \{P_K K_X + P_L L_X + \tau Q : X = X(K_X, L_X, Q), Q \leq \bar{Q}\}.$$

Let μ denote the shadow price of the environmental good and X_m denote the marginal product of factor m; the first order conditions are

$$P_K = X_K; \quad P_L = X_L;$$

$$\tau + \mu = X_Q; \quad Q = \bar{Q}$$

By assumption, scarcity of the environmental good and low government-set prices cause X to use its entire quota, $Q = \bar{Q}$ and $\mu > 0$. The shadow price is equivalent to a 'virtual' tax on the environmental good (Neary and Roberts, 1980), so the full price of Q is $P_Q = \tau + \mu$. The first order conditions imply firm X produces where the ratio of marginal products between any two inputs equals the ratio of the input prices. Factor demands can, therefore, be written as implicit functions of input prices and output,

$$K_X = K_X(P_K, P_L, P_Q, X); \quad L_X = L_X(P_K, P_L, P_Q, X); \quad Q = Q(P_K, P_L, P_Q, X)$$

Following Jones (1965), variables are expressed as their rate-of-change equivalent. This allows a highly nonlinear system to be expressed in a linear fashion assuming fairly standard economic assumptions - homogeneous of degree one production functions and competitive markets. 'Hats' over variables indicate proportional changes (e.g., $\hat{K}_X = dK_X/K_X$). Define σ_{mni} as the partial elasticity of demand for input m with respect to the price of input n in sector i. Totally differentiating X's factor demand equations yields

$$\hat{K}_X = \sigma_{KKX}\hat{P}_K + \sigma_{KLX}\hat{P}_L + \sigma_{KQX}\hat{P}_Q + \hat{X}$$

$$\hat{L}_X = \sigma_{LKX}\hat{P}_K + \sigma_{LLX}\hat{P}_L + \sigma_{LQX}\hat{P}_Q + \hat{X}$$

$$\hat{Q} = \sigma_{QKX}\hat{P}_K + \sigma_{QLX}\hat{P}_L + \sigma_{QQX}\hat{P}_Q + \hat{X}.$$

which can be combined to get

$$\hat{K}_X - \hat{Q} = \theta_{XK}(e_{KKX} - e_{QKX})\hat{P}_K + \theta_{XL}(e_{KLX} - e_{QLX})\hat{P}_L + \theta_{XQ}(e_{KQX} - e_{QQX})\hat{P}_Q \tag{1}$$

$$\hat{L}_X - \hat{Q} = \theta_{XK}(e_{LKX} - e_{QKX})\hat{P}_K + \theta_{XL}(e_{LLX} - e_{QLX})\hat{P}_L + \theta_{XQ}(e_{LQX} - e_{QQX})\hat{P}_Q \tag{2}$$

where θ_{im} is the share of i's revenue paid to input m (e.g., $\theta_{XK} = (P_K K_X)/(P_X X)$) and e_{mni} are Allen elasticities of substitution between inputs m and n, defined by $e_{mni} = \sigma_{mni}/\theta_{im}$. The measure of dependency on the environmental input is given by $\theta_{XQ} = \frac{Q(\tau+\mu)}{P_X X}$, which includes revenue paid directly to the government, $\frac{\tau Q}{P_X X}$ and rents associated with use of the environment, $\frac{\mu Q}{P_X X}$. If firms engage in rent-seeking behavior, these rents go to the government; otherwise, rents accrue to owners of firms granted the right to use the environment by the government.

Production of Y only uses capital and labor and is described by

$$\hat{K}_Y - \hat{L}_Y = \sigma_{KLY}(\hat{P}_L - \hat{P}_K) \tag{3}$$

Constant returns to scale imply

$$P_X X = P_K K_X + P_L L_X + P_Q Q$$

$$P_Y Y = P_K K_Y + P_L L_Y$$

which can be differentiated and divided by i's industry revenue to get

$$\hat{X} + \hat{P}_X = \theta_{XK}(\hat{P}_K + \hat{K}_X) + \theta_{XL}(\hat{P}_L + \hat{L}_X) + \theta_{XQ}(\hat{P}_Q + \hat{Q}) \tag{4}$$

$$\hat{Y} + \hat{P}_Y = \theta_{YK}(\hat{P}_K + \hat{K}_Y) + \theta_{YL}(\hat{P}_L + \hat{L}_Y) \tag{5}$$

Totally differentiating the production functions, dividing by total output, multiplying each term by the appropriate form of unity, and assuming factors earn their marginal products gives

$$\hat{X} = \theta_{XK}\hat{K}_X + \theta_{XL}\hat{L}_X + \theta_{XQ}\hat{Q} \tag{6}$$

$$\hat{Y} = \theta_{YK}\hat{K}_Y + \theta_{YL}\hat{L}_Y. \tag{7}$$

Capital and labor are supplied inelastically at levels $\bar{K}$ and $\bar{L}$. The resource constraints are

$$\bar{K} = K_X + K_Y; \quad \bar{L} = L_X + L_Y$$

which can be totally differentiated to yield

$$\lambda_{KX}\hat{K}_X + \lambda_{KY}\hat{K}_Y = 0 \tag{8}$$

$$\lambda_{LX}\hat{L}_X + \lambda_{LY}\hat{L}_Y = 0 \tag{9}$$

where λ_{mi} denotes the share of factor m employed in industry i (e.g., $\lambda_{KX} = K_X/\bar{K}$).

Equations (1)-(9) have 12 variables: $\hat{X}$, $\hat{Y}$, $\hat{K}_X$, $\hat{K}_Y$, $\hat{L}_X$, $\hat{L}_Y$, $\hat{Q}$, $\hat{P}_K$, $\hat{P}_L$, $\hat{P}_Y$, $\hat{P}_X$, and $\hat{P}_Q$. The terms of trade are fixed by the small country assumption, and environmental quotas are determined by policy. Therefore, P_X, P_Y, Q, are exogenous. The system reduces to nine equations and nine unknowns allowing it to be solved for changes in prices and quantities following exogenous parameter changes. As in all price systems, changes are relative to a numeraire, which in this case is a price index of the exogenous world prices.

3 Results

If the environmental input is not scarce, such that its shadow price equals zero, the model collapses to the standard Hecksher-Ohlin model, and it is consistent with such properties as the Rybczinski and Stopler-Samuelson Theorems. When $\hat{P}_Q$ is positive, changes in factor returns depend on the relative factor intensities of each sector and the effect of policies on the relative environmental rents. Equations (4) and (5) can be combined with equations (6) and (7) to get

$$\hat{P}_L = \frac{-\theta_{YK}\theta_{XQ}\hat{P}_Q}{\theta_{XL}\theta_{YK} - \theta_{XK}\theta_{YL}}. \tag{10}$$

$$\hat{P}_K = \frac{\theta_{YL}\theta_{XQ}\hat{P}_Q}{\theta_{XL}\theta_{YK} - \theta_{XK}\theta_{YL}} \tag{11}$$

Note that $\hat{P}_L$ and $\hat{P}_K$ will always have opposite signs that depend on $\hat{P}_Q$, which can be written in terms of exogenous parameters,

$$\hat{P}_Q = -\frac{\hat{Q}_X(\lambda_{KY}\lambda_{LX} - \lambda_{KX}\lambda_{LY})(\theta_{YK}\theta_{XL} - \theta_{XK}\theta_{YL})}{\theta_{XQ}\Delta} \tag{12}$$

$\Delta = A + B + C + D + E + F + G$; $A = e_{LLX}(-\theta_{YK}\theta_{XL}\lambda_{KY}\lambda_{LX})$; $B = e_{KKX}(-\theta_{YL}\theta_{XK}\lambda_{LY}\lambda_{KX})$; $C = e_{QQX}((\theta_{YL}\theta_{XK} - \theta_{YK}\theta_{XL})(\lambda_{KY}\lambda_{LX} - \lambda_{KX}\lambda_{LY}))$;

$D = \sigma_{KLY}(\lambda_{KY}\lambda_{LY})$; $E = e_{KLX}(\theta_{YK}\theta_{XL}\lambda_{LY}\lambda_{KX} + \theta_{YL}\theta_{XK}\lambda_{LX}\lambda_{KY})$; $F = e_{QKX}(\theta_{YL}\theta_{XK}(\lambda_{KX}\lambda_{LY} - \lambda_{LX}\lambda_{KY}) + \lambda_{KX}\lambda_{LY}(\theta_{XK}\theta_{YL} - \theta_{XL}\theta_{YK}))$; $G = e_{QLX}(\theta_{YK}\theta_{XL}(\lambda_{LX}\lambda_{KY} - \lambda_{KX}\lambda_{LY}) + \lambda_{LX}\lambda_{KY}(\theta_{XL}\theta_{YK} - \theta_{XK}\theta_{YL}))$. Note that $e_{mni} = e_{nmi}$ (Allen, 1938). Equation (12) shows an inverse relationship between quantity of the environmental input and its price and represents a demand curve for the environmental input. For the purposes here, it is assumed that the rate charged by the government for the environmental input does not change, thus changes in P_Q are entirely from changes in the shadow price.

The position of Δ in the denominator causes problems. In lower dimensioned models with either three factors and one good (e.g., Mieszkowski (1966)) or models with two factors and two goods (e.g., Harberger (1962) and Fullerton and Metcalf (2002)), the term in the denominator (often referred to as D in the mentioned papers) has an unambiguous sign. In models with two goods and three factors, however, such as this one, Fullerton and Heutel (2007), and Fullerton and Heutel (2010), the denominator can be either positive, negative, or zero. Fullerton and Heutel (2007) is largely an exploration of when the denominator can switch signs, but gives no mention of the possibility of it being zero. That possibility and its implications are explored here.

While seemingly complicated, each element of Δ can be signed with limited assumptions. For ease of exposition, assume X is labor-intensive such that $\theta_{XL}/\theta_{YL} > \theta_{XK}/\theta_{YK}$, or equivalently $\lambda_{LX}/\lambda_{LY} > \lambda_{KX}/\lambda_{KY}$. Own price elasticities are non-positive, so $e_{LLX}, e_{KKX}, e_{WWX} \leq 0$. $e_{mni} \geq 0$ if m and n are substitutes, and $e_{mni} \leq 0$ if m and n are complements. I assume labor and capital are substitutes so $e_{LKX}, e_{KLX}, \sigma_{KLY} \geq 0$. A, B, C, D, and E are therefore non-negative.[2] F is non-negative if and only if capital and the environmental input are complements. G is non-negative if and only if labor and the environment are substitutes. The sign of Δ, therefore, depends on the relative magnitudes of F and G, which depend on the substitutability of labor and capital for the environment. One result can already be stated definitively: If labor is a substitute to the environment and capital is a complement to the environment, P_L falls and P_K rises following a reduction in $\bar{Q}$.

At most, only one of the factors of production can be a complement to the environment (Allen, 1938). In fact, the results depend not on whether a factor is an absolute complement, but which factor is more complementary with (or more substitutable for) the environment. Relative elasticities of substitution and factor intensities determine the size of two effects, known as the output and substitution effects (Mieszkowski, 1967). As X contracts, relatively more labor than capital is released onto the market. Capital-intensive Y is not willing to employ these factors at current prices. To maintain full employment, the price of labor must fall in relation to the price of capital. This movement is the output effect. If P_Q rises due to increased scarcity, X substitutes towards labor and capital. The more substitutable factor will be in relatively higher demand, and its price will rise. This movement is the substitution effect. The sum of the output and substitution effects is the total impact of a policy.

Conditions exist under which a decrease in availability of the environmental input could increase returns to labor, but it is not when labor is more substi-

[2] Assuming labor and capital are substitutes allows E to be non-negative and simplifies the following discussion. If they were compliments E would be non-positive, and the magnitude of the results would change. The discussion and sensitivity analysis assume constant elasticities of substitution for capital and labor, so E merely shifts the point at which the sign of price impacts change. The main results and intuition would still hold.

tutable for the input than capital. If labor is more substitutable, reductions in Q increases the relative demand for labor but not enough to offset the total reduction in industry output. Under these conditions G is positive. $\hat{P}_L$ flattens as the substitutability increases. The denominator of (12) grows but never changes sign.

Instead, it is when capital is more substitutable with the environment (or, equivalently, labor is more complementary to the environment), that permits the returns to labor to rise. G becomes more negative the more complementary labor and the environment becomes. A decrease in Q causes an increase demand for capital, but X always demands relatively more labor (because it is labor-intensive). The price of labor might rise in relation to that of capital.[3]

While the relative substitutability of labor and capital ultimately determines the signs of $\hat{P}_L$, $\hat{P}_K$, and $\hat{P}_Q$, the relationship is not monotonic; it is hyperbolic. As labor and capital approach perfect substitutability for each other, the model exhibits a bang-bang solution typical of models with perfect substitutes. Small perturbations in factor intensities or elasticities drastically affect the incidence of environmental policies. Consider the elements of Δ that have ambiguous signs and define $\Phi = F + G$ such that

$$\begin{aligned}\Phi = {} & e_{QLX}(\theta_{YK}\theta_{XL}(\lambda_{LX}\lambda_{KY} - \lambda_{KX}\lambda_{LY}) + \lambda_{LX}\lambda_{KY}(\theta_{XL}\theta_{YK} - \theta_{XK}\theta_{YL})) \\ & -e_{QKX}(\theta_{YL}\theta_{XK}(\lambda_{LX}\lambda_{KY} - \lambda_{KX}\lambda_{LY}) + \lambda_{KX}\lambda_{LY}(\theta_{XL}\theta_{YK} - \theta_{XK}\theta_{YL}))\end{aligned} \tag{13}$$

Interest is in the relative substitutability of factors, so define $\gamma = e_{QKX}/e_{QLX}$. For $\gamma < 1$, labor is more substitutable than capital for the environmental input. $\gamma = 1$

[3] Mieszkowski (1967) shows in a two input model of tax incidence that there is no substitution effect when production in the affected industry uses a fixed-coefficient production function, and there is no output effect when industries have equal factor intensities.

implies that factors are equally substitutable for the environmental input, and $\gamma > 1$ implies that labor is less substitutable than capital for the environmental input.

The terms in parentheses are positive because X is labor-intensive. If $\gamma = 0$, Φ and Δ are positive if and only if labor and the environmental input are substitutes. Regardless of initial substitutability, Φ switches signs as γ increases, heading to either positive or negative infinity in the limit; thus, the denominator of Δ also switches signs as γ increases. The behavior of Δ causes adjustments in prices to be hyperbolic with an asymptote where $\Delta = 0$. The presence of an asymptote has implications for the burden of environmental policies and reduction in resources available. Consider a case where Δ is initially negative, such that $\hat{P}_L$ is initially positive. As $\Delta \to 0$ from the left, $\hat{P}_L \to \infty$ and $\hat{P}_K \to -\infty$. As $\Delta \to 0$ from the right, $\hat{P}_L \to -\infty$ and $\hat{P}_K \to \infty$.

The location of the asymptote depends on elasticities and factor shares, which likely change over time. A factor can go from being a large net benefactor to a large net loser following a shock with small perturbations in the economy. Note that factor employments are bound by resource constraints, and the resource constraints bind final production. Employment levels can shift drastically from one industry to the other for values that produce asymptotic behavior in prices, but they cannot approach infinity.

While most studies report welfare effects that depend on relative factor intensities and substitution possibilities, none have specifically addressed this asymptotic property though it exists in models with at least two goods and three inputs. Near the asymptote, factors of production are perfect substitutes for the environmental input, and a bang-bang solution should be expected. The model is stable away from the asymptote, making the question of where the economy operates an important empirical question. If one parameterization of a model produces a positively signed result and another parameterization produces a negatively signed result, the asymptote must have been crossed. In those cases, the implied assumption is that the economy is operating near the threshold. This point is illustrated with a numerical example using land reform in Jordan and water as the environmental input.

4 Numerical example: Agricultural reform in Jordan

4.1 Background

Land reforms that began in 1962 when water issues were less pressing encouraged the formation of small farms in attempts to settle families, including Bedouins in the Highlands and Palestinian refugees. In the 1970s and 1980s irrigated agriculture thrived due to improvement of irrigation facilities, cheap labor from Egypt, cheap land, and low electricity rates. Revenues from vegetable farming increased by a factor of ten; revenues from fruit farming doubled (Venot and Molle, 2008). Today, irrigated agriculture uses about sixty-five percent of total water used annually in Jordan (Khaleq, 2008).

This 'Super Green Revolution' ended for Jordan in the 1990s as competition increased from Turkey, Lebanon, and Syria. The first Gulf War and reaction from the use of treated wastewater in irrigating vegetables caused declining demand for Jordanian crops (Molle et al., 2008; Venot and Molle, 2008). Agriculture's share of GDP fell from 8.1 percent in 1991 to 3 percent in 2007 (FAO, 2010).

Declining revenues and employment levels have led to increased opposition to use of water for agriculture (Haddadin et al., 2006), causing the Jordan government to switch its policy focus from enhancing water supply to managing water demand. A 1994 plan to reform the agricultural sector and a 1997 water development strategy emphasized the need for economic instruments to correct inefficiencies in water use, particularly the need to price water for irrigation appropriately. Some price reforms have taken place, including the Groundwater Control Bylaw, Number (85) in 2002, but current revenues from water sales only cover 72 percent of operating and maintenance costs of the water delivery system. Furthermore, monitoring of wells is not reliable, and the country is dotted with illegal wells that are not monitored at all (The Hashemite Kingdom of Jordan, 2004; Molle et al., 2008).

Instead of price controls, the country relies heavily on crop-based quotas that have been consistently lowered. In 1990, quotas allowed each plot of land 2 mm of water per day for vegetables grown between mid-April and mid-December and 4 mm and 8 mm per day for citrus and bananas grown between May and October. These quotas were matched with policies that limited the expansion of agricultural land, leading to actual quotas of 4800 m^3/ha for vegetables, 9500 m^3/ha for citrus, and 17,200 m^3/ha for bananas. Droughts from 1997 to 1999 caused quotas to be reduced 25 percent for vegetables and citrus and 15 percent for bananas. Annual allocations fell by 25 percent in 2000 and 2003, and by 40-50 percent during the summers of 2001 and 2003. In 2004, new quotas were set at 3600 m^3/ha for vegetables, 7650 m^3/ha for citrus, and 12,550 m^3/ha for bananas (Haddadin et al., 2006; Molle et al., 2008).

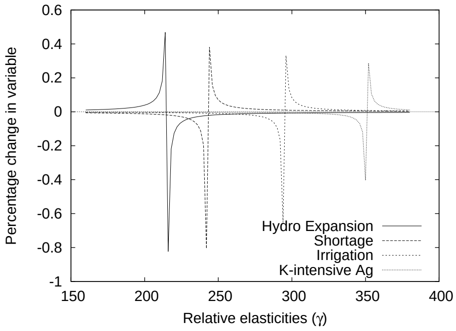
Farmers in Jordan have responded to quota reductions in water by investing in new techniques, including capital-intensive irrigation systems. Large corporate farming has replaced small-holder farming in much of the country. These changes have led to division within the country. Farmers lobby for improvements to the irrigation system, and urbanites call for stricter agricultural quotas. Meanwhile, poor farmers resist tradable water rights in fear that they will price them out of access to what little water they have (Venot et al., 2007).

4.2 Data and parameterization

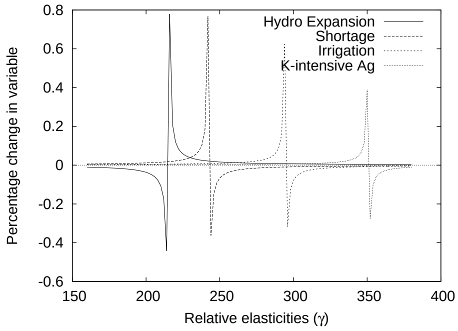
Table 1 gives parameter values used in the simulation for Jordan. Factor intensities used in the analysis are based on a social accounting matrix provided by Omar Feraboli and discussed in Feraboli and Trimborn (2008) and supplemented with data from Jordan's Ministry of Water. Labor and capital embedded in intermediate inputs is included following Valentinyi and Herrendorf (2008). For purposes of this study, industries are aggregated into 'agriculture' (Ag) and a catchall 'industry' (Ind) sector.

4.3 Numerical results

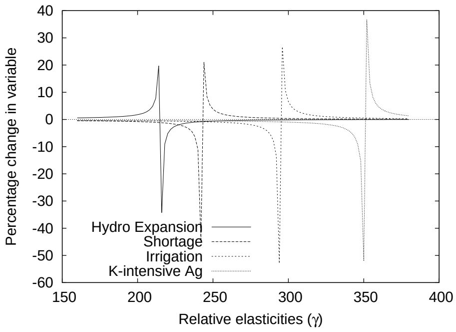
Impacts are calculate for a 25 percent reduction in water supplied to agriculture as was experienced in the late 1990s and early 2000s. According to the superposition principle, in a linear system, the impact of two simultaneous events is the sum of impacts that would have occurred if each event occurred independently. Larger changes in the water supply will, therefore, lead to scaled impacts of the ones reported here. For example, a two percent reduction in water supply causes double



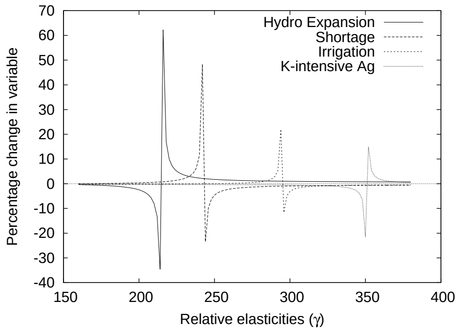
(a) Price of Labor



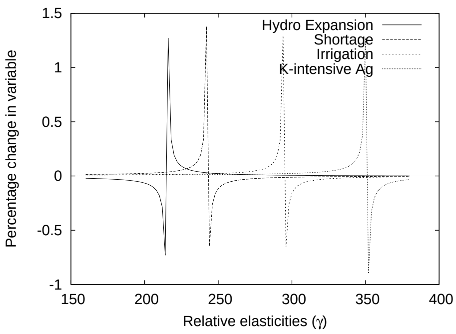
(b) Price of Capital



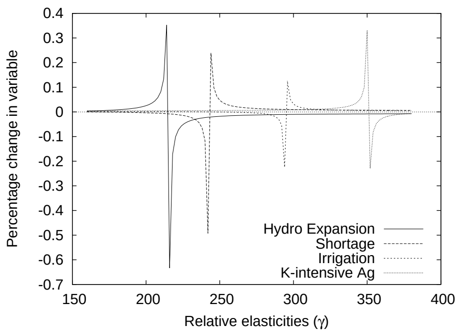
(c) Labor employed in X



(d) Capital employed in X



(e) Labor employed in Y



(f) Capital employed in Y

Figure 1: Numerical results

Table 1: Elasticities of substitution and base case factor shares

parameter	value	source
e_{LLAg}	-2.230	Hammonds et al. (1973)
e_{KKAg}	-0.480	Berndt and Wood (1975)
e_{QQAg}	-0.420	Schoengold et al. (2006)
e_{KLAg}	0.240	Berrittella et al. (working)
e_{QLAg}	1.000	parameterized
e_{QKAg}	γe_{QLAg}	parameterized
σ_{KLInd}	1.190	Berrittella et al. (working)
θ_{AgK}	0.469	based on Feraboli and Trimborn (2008)
θ_{AgL}	0.530	based on Feraboli and Trimborn (2008)
θ_{AgQ}	0.001	based on Feraboli and Trimborn (2008)
θ_{IndK}	0.500	based on Feraboli and Trimborn (2008)
θ_{IndL}	0.500	based on Feraboli and Trimborn (2008)
λ_{KAg}	0.071	based on Feraboli and Trimborn (2008)
λ_{KInd}	0.929	based on Feraboli and Trimborn (2008)
λ_{LAg}	0.080	based on Feraboli and Trimborn (2008)
λ_{LInd}	0.920	based on Feraboli and Trimborn (2008)

the impact of a one percent reduction in water supply. Results are shown in figure 1. The relative substitutability of capital and labor for water are modeled by varying $\gamma = e_{QKAg}/e_{QLAg}$.

Four scenarios are considered. On figure 1, the scenarios are as follows, with peaks from left to right: 1) The first scenario, Hydrological Expansion, considers an increase in water supply when agriculture is relatively labor intensive (employing 50 percent more labor than currently). This scenario is typical of Jordan's water policy up until the 1980s. During this period, the focus was expanding water supply to agriculture through large national irrigation projects and expanded use of ground water. 2) The second scenario, 'Shortage', shows the results of a water reduction when agriculture is more labor-intensive than today, but less labor-intensive than the first scenario (25 percent more labor employed than currently).

This scenario is typical of the reduction in water quotas agriculture faced in the late 1990s. 3) The third scenario, 'Irrigation', shows a water shortage with capital and labor ratios consistent with current data. Compared to the 'Shortage' scenario, it represents a period following large on-farm investments in irrigation equipment. 4) The last scenario, 'K-intensive Agriculture', shows the results of a water reduction assuming a 50 percent increase in on-farm capital invested over current levels.

The graphs clearly show the asymptote. Numeric approximation affects the height of each on the graphs, but they all represent the same movements toward positive or negative infinity. As γ increases, the economy reaches a threshold, or asymptote, at which point labor and capital are equally substitutable for water. Around the asymptote the model exhibits bang-bang solutions consistent with models in which inputs are perfect substitutes. In the Hydrological Expansion scenario this occurs near $\gamma = 215$. Small changes in prices lead to large changes in quantities of factors demanded. Benefits of the water expansion shift from labor to capital. If γ is above this threshold the substitution effect dominates the output effect. The price of labor falls, and the price of capital rises. Because capital is a good substitute for water in agriculture, agriculture hires more capital. The price of capital rises. For values of γ below the asymptote, increased water cause agriculture to become even more labor-intensive; for values of γ above the asymptote, increases in water cause agriculture to become more capital-intensive. Shocks are larger nearer the asymptote, but approach zero for small, large, and negative values of γ. In all scenarios, the threshold γ is large, and it can be assumed Jordan's economy lies to the left of the threshold. Nonetheless, the figures are instructive. A modeler could, for example, first assume the water-labor ratio is fixed ($e_{QLX} = 0$) and the water-capital ratio is not ($e_{QKX} > 0$), then assume the opposite such that $e_{QLX} > 0$ and $e_{QKX} = 0$. In this case, results would likely change signs, and the asymptote would be crossed.

Jordan's water policies in the 1960s and 1970s focused on creating jobs through the expansion of irrigated agriculture. The country received financial and planning support from the United Nations and foreign aid agencies. The efforts were successful, increasing employment in agriculture and raising rural incomes. As the relative wage rose, capital became relatively cheap. This helped fuel large projects such as the King Talal Dam, expansion of the East Ghor Canal (later named the King Abdullah I Canal), and improvements in municipal water systems, all of which were built using urban-owned capital. This is consistent with the Hydrological Expansion scenario that shows increased labor employment in agriculture and increased capital employment in industry.

Severe drought in the late 1990s and early 2000s prompted reductions in water quotas to agriculture. These reductions hurt rural labor that had become dependent on agriculture. Labor employment fell in agriculture as many families moved to the cities, particularly to the capitol city of Amman. The negative impact on labor was mitigated somewhat due to its role as a substitute for both water and capital, which become more expensive. Returns to labor fell as capital became a better substitute for water in agriculture (as γ increased). This is consistent with the shortage scenario. For low levels of γ, the output effect dominates the substitution effect, and the burden falls on labor.

Corporate export-oriented farming has largely replaced small-holder farming, a change that coincided with large investments in on-farm irrigation infrastructure. At the same time, returns to labor in the agricultural sector fell, and today most farm labor is done by low-wage immigrant labor.[4] Jordan's shift in farming practices indicate increasing substitutability of capital for water. Today, the focus of Jordanian agriculture is enhanced efficiency of on-farm water use, rather than acquiring new sources of water.

The Irrigation scenario shows what happens as agriculture becomes more capital-intensive. The asymptote shifts right causing two effects. First, the range increases over which the output effect dominates the substitution effect. Labor is more likely to bear the burden of the shock. Second, more capital-intensive farming may insulate both factors from negative shocks. For values to the left of the asymptote, the size of the impact for any given γ is smaller. Further, as agriculture becomes more capital-intensive, it becomes harder to find ways to substitute capital for water near the limits of irrigation technology. The economy will operate at a lower γ. As factor-intensities of the two industries converge, the change in both factor prices goes to zero, so $\hat{P}_Q$, $\hat{P}_K$, and $\hat{P}_L$ go to zero as well.

The K-intensive Ag scenario shows what happens with a 50 percent increase in capital employed in agriculture and a reduction in water supply. Changes in prices are like the other water-reduction scenarios. The rightward shift causes smaller changes in prices. Labor employment trends are the same - labor shifts from agriculture to industry. Differences occur, however, in capital employment. In this scenario, capital employed in agriculture falls and is re-employed in industry. This change occurs because capital is now a large enough part of agriculture that agriculture is significantly hurt by capital's increased price. It reduces labor and capital employment. If agriculture employs enough capital, these results flip.

[4] Eighty-nine percent of permanent agriculture in Jordan is foreign (Department of Statistics Jordan, 2007).

Water shortage would cause price of capital to fall.

The discussion has been framed around water reductions. This has been the norm within Jordan, but investments are once again being made to enhance the water supply. Among the most promising for agriculture is the use of reclaimed wastewater. Approximately 65 percent of households in Jordan are connected to wastewater treatment plants. Effluent from treatment plants is released into the King Talal Reservoir where it is mixed with water from the Zarqa River. The water is used to irrigate farms in the middle and southern sections of the Jordan Valley.[5] According to this model, increasing water to agriculture will primarily benefit labor, because even though capital is a better substitute for water, it is not substitutable enough. Labor is also a substitute for water and capital. The inclination will be to shed capital and hire more labor in the agricultural sector. Cheaper capital will also encourage investment in the industrial sector, helping to fuel long term growth.

5 Conclusion

The most important implication of these results is the difference between policies that occur near the asymptote and those that occur away from the asymptote. Near the asymptote, winners win big, and losers lose big. The distributional effects of such policies are large. Away from the asymptote, winners and losers are less distinguishable, and in the limit, impacts to both factors go to zero. Policies that encourage capital investment in agriculture hurt low-skilled labor in the short run, but in the long run, reduce exposure to damages from a water shortage.

[5] Over time the quality of the mixed water has deteriorated due to declining inflows from the Zarqa River and increased effluents in the river (Daoud, 2000).

The Harberger model is useful for policy analysis, but the work here shows the model's sensitivity to parameter changes, particularly in higher dimension models with multiple ways to substitute factors of production. Users of the model should be aware of the asymptote discussed, and know that if the results change signs following changes in parameter values, it is most likely due to hyperbolic behavior rather than gradual change. The asymptote was likely crossed, and intermediate values would yield solutions that head towards negative or positive infinity. 'Near the asymptote' is the relevant range for discussion.

This paper shows the incidence of a reduction in water to an industry depends on relative factor shares employed in the industry and relative elasticicities of substitution between factors. The burden of a drought falls on the factor used intensively in the water dependent industry, most often agriculture. The incidence of drought varies between developing and developed countries. In developing countries with labor-intensive farming, labor will bear the burden. In developed countries with capital-intensive farming, capital will bear the burden. If the less intensive factor is a good substitute for water, the incidence reverses. Capital bears the burden in developing countries, and labor bears the burden in developed countries.

Capital investments in agriculture are important for developing countries subject to drought. They reduce the exposure of all factors to damages. The long run effects on growth are even more promising. Investments in agriculture increase the range over which capital is protected from the burden of drought. Relative returns to capital increase, creating more investment throughout the economy. Agriculture's share of GDP will fall, creating a more industrialized economy. In the short run, the costs of adjustment may be large and some may oppose the decline of agriculture. Such economies, however, are not only less dependent on water, but also tend to experience higher growth rates.

These trends can be seen in a number of countries facing water scarcity; Jordan has been offered as one example. The past twenty years have seen drastic reductions in per capita water available in Jordan. Agriculture, the largest user of water, has seen allocations fall by about 25 percent. A national campaign for 'more crop per drop' led to large expansion of irrigation infrastructure, which facilitated the rise of corporate farming. With wealthy capital owners as the current face of farming in Jordan, water policies are mired in politics. Continuous water shortages are causing agriculture's share of employment and GDP to fall, and will eventually lead to less capital investment in agriculture and more water available for cities and industry. As a hint of what may lie ahead, Jordan's water campaign has been re-dubbed 'more income per drop.'

References

Allen, R G D (1938), *Mathematical analysis for economists.* Macmillan, London.

Barbier, Edward (2004), "Water and economic growth." *Economic Record*, 80, 1–16.

Berndt, Ernst R and David O Wood (1975), "Technology, Prices, and the Derived Demand for Energy." *The Review of Economics and Statistics*, 57, 259–268.

Berrittella, Maria, Arjen Y Hoekstra, Katrin Rehdanz, Roberto Roson, and Richard S J Tol (working), "The economic impact of restricted water supply: A computable general equilibrium analysis." *Working Paper FNU-93 (revised)*, URL `www.fnu.zmaw.de/GTAP-EF-W.5680.0.html`.

Chisholm, R.A. (2010), "Trade-offs between ecosystem services: Water and carbon in a biodiversity hotspot." *Ecological Economics.*

Copeland, B.R. and M.S. Taylor (2003), *Trade and the environment: Theory and evidence.* Princeton Univ. Press.

Daoud, Ra'ed (2000), "Water Resources and Their Economics in Jordan." Technical report, Royal Scientific Society.

Department of Statistics Jordan (2007), "Number and area of agricultural holdings by type of holding and total area size class of the holding." URL `www.dos.gov.jo/agr/agr_a/haiawanieh/tabels/tab1-2.pdf`.

Esrey, S.A., J.B. Potash, L. Roberts, and C. Shiff (1991), "Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma." *Bulletin of the World Health organization*, 69, 609.

Falkenmark, M., J. Lundqvist, W. Klohn, S. Postel, J. Wallace, H. Shuval, D. Seckler, and J. Rockström (1998), "Water scarcity as a key factor behind global food insecurity: Round table discussion." *Ambio*, 27, 148–154.

FAO (2010), "FAOSTAT, Food and Agricultural Organization of the United States." accessed online, URL `http://faostat.fao.org`.

Feraboli, Omar E and Tim Trimborn (2008), "Trade Liberation and Income Distribution: A CGE Model for Jordan." *International Trade and Finance Association Working Papers.*

Fewtrell, L., R.B. Kaufmann, D. Kay, W. Enanoria, L. Haller, J.M. Colford, et al. (2005), "Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis." *The Lancet infectious diseases*, 5, 42–52.

Fullerton, D. and G. Heutel (2007), "The general equilibrium incidence of environmental taxes." *Journal of Public Economics*, 91, 571–591.

Fullerton, D. and G.E. Metcalf (2002), "Tax incidence." *Handbook of public economics*, 4, 1787–1872.

Fullerton, Don and Garth Heutel (2010), "The General Equilibrium Incidence of Environmental Mandates." *American Economic Journal: Economic Policy*, 2, 64–89.

Fullerton, Don and Gilbert E. Metcalf (2001), "Environmental controls, scarcity rents, and pre-existing distortions." *Journal of Public Economics*, 80, 249–267.

Haddadin, Munther J, Sami J Sunna', and Hani A Al Rashid (2006), "Development of Water Resources for Irrigation." In *Water Resources in Jordan* (Munther J Haddadin, ed.), RFF press.

Hammonds, T M, R Yadav, and C Vathana (1973), "The Elasticity of Demand for Hired Farm Labor." *American Journal of Agricultural Economics*, 55, 242–245.

Harberger, Arnold C (1962), "The Incidence of the Corporation Income Tax." *The Journal of Political Economy*, 70, 215–240.

Jones, Ronald W (1965), "The Structure of Simple General Equilibrium Models." *The Journal of Political Economy*, 73, 557–572.

Khaleq, Rania A Abdel (2008), "Water Demand Management in Jordan." Technical report, Jordan Ministry of Water and Irrigation, Amman.

Mieszkowski, P. (1972), "The property tax: an excise tax or a profits tax?" *Journal of Public Economics*, 1, 73–96.

Mieszkowski, Peter M (1966), "The comparative efficiency of tariffs and other tax-subsidy schemes as a means of obtaining revenue or protecting domestic production." *Journal of Political Economy*, 74, 587–599.

Mieszkowski, Peter M (1967), "On the Theory of Tax Incidence." *The Journal of Political Economy*, 75, 250–262.

Molle, F., J.P. Venot, and Y. Hassan (2008), "Irrigation in the Jordan Valley: Are water pricing policies overly optimistic?" *agricultural water management*, 95, 427–438.

Neary, J.P. and K.W.S. Roberts (1980), "The theory of household behavior under rationing." *European Economic Review*, 13, 25–42.

Prüss-Üstün, A (2008), "Safer water, better health: costs, benefits and sustainability of interventions to protect and promote health." Technical report, World Health Organization, Geneva.

Rosegrant, Mark W and Hans Binswanger (1994), "Markets in tradable water rights: potential for efficiency gains in developing country water resource allocation." *World development*, 22, 1613–1625.

Schoengold, Karina, David L Sunding, and Georgina Moreno (2006), "Price elasticity reconsidered: Panel estimation of an agricultural water demand function." *Water Resources Research*, 42, 1–10.

Seagraves, J.A. and K.W. Easter (1983), "Pricing Irrigation Water in Developing Countries." *Water Resorces Bulletin*, 19, 663–672.

Seung, C.K., T.R. Harris, J.E. Englin, and N.R. Netusil (2000), "Impacts of water reallocation: A combined computable general equilibrium and recreation demand model approach." *The Annals of Regional Science*, 34, 473–487.

Shoven, J.B. and J. Whalley (1984), "Applied general-equilibrium models of taxation and international trade: an introduction and survey." *Journal of Economic Literature*, 1007–1051.

The Hashemite Kingdom of Jordan (2004), "National water master plan." Technical report, German Agency for Technical Cooperation.

Valentinyi, Ákos and Berthold Herrendorf (2008), "Measuring factor income shares at the sectoral level." *Review of Economic Dynamics*, 11, 820–835.

Venot, J.P. and F. Molle (2008), "Groundwater depletion in the jordan highlands: can pricing policies regulate irrigation water use?" *Water resources management*, 22, 1925–1941.

Venot, J.P., F. Molle, and Y. Hassan (2007), "Irrigated agriculture, water pricing and water savings in the Lower Jordan River Basin (in Jordan)." *Comprehensive Assessment of Water Management in Agriculture Research.*

Wada, Y, L P V van Beek, C M van Kempen, J W T M Reckman, S Vasak, and M F P Bierkens (2010), "Global depletion of groundwater resources." *Geophysical Research Letters*, in press.