Theoretical Mathematics & Applications, Vol. 13, No. 2, 2023, 1-15
ISSN: 1792-9687(print), 1792-9709(online)
https://doi.org/10.47260/tma/1321
Scientific Press International Limited

Decentralized Environmental Regulation in a Model with Increasing-Returns-to-Scale

Mitch Kunce[1]

Abstract

In economics, homothetic functions are generally used to represent production. Homogeneous production functions are a subset. A production function is homogeneous of degree α when all inputs are changed in the same proportion and resulting output changes by the αth power of the input change. Convention envisions homogeneity of degree 1, constant-returns-to-scale. Herein, we alter convention for increasing-returns-to-scale, $\alpha > 1$. With aggregate increasing-returns-to-scale, symmetric regions, in a first-best Nash equilibrium, subsidize capital and *overprotect* the regional environment. Second-best fiscal structures are also examined.

JEL Classification numbers: H20, H71, H73
Keywords: Environmental federalism, Inter-jurisdictional competition, Increasing-returns-to-scale, Homothetic functions.

[1] Douglas**Mitchell** Econometric Consulting, Laramie, WY USA.

Article Info: *Received:* July 26, 2023. *Revised*: August 15, 2023.
Published online: August 28, 2023.

1. Introduction

Standard theory, in the setting of inter-jurisdictional competition, predicts a *race-to-the-bottom* when devolved regions, in their vehemence to attract commerce, forward place-based policies to reduce business costs in the form of fiscal structures that underprovide local public goods and suboptimal pollution standards that lower regional environmental quality. The current body of empirical evidence, however, does not provide convincing support for the race within the context of fiscal or environmental federalism (Dijkstra and Fredriksson, 2010; Holzinger and Sommerer, 2011; Costa-Font et al., 2015; Chirinko and Wilson, 2017). Why then, in contrast to theory, are we not finding this race to the bottom? Holzinger and Sommerer (2011) summarized a number of views explaining the mixed empirical results within the environmental regulation setting. Also, theoretical models that support this environmental race, generally, presume aggregate jurisdictional technologies exhibiting constant-returns-to-scale (CRS). What if we relax this modeling assumption allowing for increasing-returns-to-scale (IRS)? There is moderate empirical evidence supporting aggregate IRS, for traditional production inputs, at the jurisdictional level (Perälä, 2008). In this paper, symmetric regions in a Nash equilibrium may *overprotect* the environment under aggregate IRS and first-best taxation. The next section characterizes the model and discusses the Nash results.

2. The model

The model builds on the framework of Burbidge and Cuff (2005) allowing for the choice of environmental standards. Suppose for simplicity that an area's economy consists of two symmetric regions (indexed by $i = 1, 2.$) where the jurisdictions are large enough that pollution generated in one region does not spill-over to the other.[2] The population is fixed in each region and identical residents own equal shares of a productive fixed factor, L_i, that is supplied to production inelastically. The fixed factor is taxed with a free-to-vary source based unit tax t. Each region produces a homogeneous numeraire private good that is sold in a national market. Production requires perfectly mobile capital inputs, K_i, the regional fixed factor, L_i, and allowed pollution emissions, E_i, which are treated as an input to production akin to Oates and Schwab (1988).[3] The fixed capital stock, $\overline{K}$, is owned in equal regional shares, η_i, by residents.[4]

[2] Focusing on symmetric regions allows us to avoid the potential inefficiencies in which Tiebout-type regions are inefficiently organized or incongruously stratified by class, information, wealth endowment or size. Moreover, if inefficiencies arise in a symmetric setting, they are likely to be exacerbated in an asymmetric construct. Lastly, this pollution externality fits Oates (2002) 'Benchmark Case 2: Local Public Goods'. This benchmark defines the best case for decentralized environmental standard setting.

[3] Cropper and Oates (1992) considered this approach the standard in environmental economics.

[4] Following convention, the model focuses on the allocation of a fixed stock rather than new capital formation. Additionally, from this point forward the use of region subscripts will be limited, however functions are understood to be region specific.

In this devolved environmental regulation milieu, local authorities set a standard for regional environmental quality. For example, regions may specify an allowable aggregate level of the concentration of pollutants. Herein, this level is captured by, E, which affects both local production and regional welfare. Scaling the input, E, is presumed to have increasing affects to regional output. Realistic? Kunce and Shogren (2005) described the case of coal bed methane (CBM) development in Northeast Wyoming in the 2000s. Coal bed methane is natural gas found in coal seams, generally saturated with ground water containing levels of saline, arsenic and barium. Extraction of the gas brings to the surface large volumes of the polluted water that is either re-injected or monitored and discharged to pool. Prior to 2000, discharge permits were limited and costly re-injection technologies were encouraged. During the CBM boom, monitoring became more lax, discharge permitting increased and output of natural gas increased markedly. For example, Wyoming CBM production went from 32 billion cubic feet in 1998 to over 384 billion cubic feet in 2006 (WOGCC, 2023). Lax local water standards and monitoring are prime examples of a regulation input that can produce increasing returns.

Both regions possess the same production technology,

$$F(\lambda L, \lambda K, \lambda E) = \lambda^{\alpha} F(L, K, E), \tag{1}$$

which is homogeneous of degree $\alpha > 1$.[5] When $\alpha = 1$ the production function exhibits constant-returns-to-scale (CRS). Firms and regional authorities view α as parametric. Regional production possesses all conventional curvature properties hence all marginal products F_L, F_K, F_E are positive and diminish F_{LL}, F_{KK}, $F_{EE} < 0$, where subscripts denote partial derivatives. Moreover, all inputs are technical complements F_{LK}, F_{LE}, $F_{KE} > 0$. Euler's theorem establishes,

$$\alpha F(L, K, E) = F_L L + F_K K + F_E E \quad \text{for } \lambda \text{ normalized to } 1, \tag{2}$$

where differentiating equation (2) with respect to each input yields, [6]

$$(\alpha - 1)F_L = F_{LL} L + F_{LK} K + F_{LE} E, \tag{3}$$

$$(\alpha - 1)F_K = F_{LK} L + F_{KK} K + F_{KE} E, \tag{4}$$

$$(\alpha - 1)F_E = F_{LE} L + F_{KE} K + F_{EE} E. \tag{5}$$

---

[5] See Kunce (2022) for an example of a model that incorporates strictly external economies.

[6] Young's theorem allows us to define *all* common mixed partial derivatives as equal, for example $F_{LK} = F_{KL}$.

From equation (2), $F_E E$ represents the additional output generated from emission allowances. Following Oates and Schwab (1988), we ration this environmental rent to regional residents.
In order for marginal products to be downward sloping, the magnitude of α is restricted by (for example rearranging equation (4)),

$$F_{KK}K = (\alpha - 1)F_K - (F_{LK}L + F_{KE}E), \tag{6}$$

where the relative magnitude of the marginal product term $(\alpha - 1)F_K$ must be sufficiently small,

$$(\alpha - 1)F_K < (F_{LK}L + F_{KE}E)\,. \tag{7}$$

Under CRS, the left-side term in equation (7) vanishes. Examining equation (6), α has an upper bound ensuring F_{KK} is negative.
Similarly, technical complementarity requires (again, for example, rearranging equation (4)),

$$F_{KE}E = ((\alpha - 1)F_K - F_{KK}K) - F_{LK}L\,, \tag{8}$$

where,

$$((\alpha - 1)F_K - F_{KK}K) > F_{LK}L\,.\ ^{7} \tag{9}$$

Capital is perfectly mobile within and across regions (at least in the long run) following,

$$K_1 + K_2 = \overline{K}\,. \tag{10}$$

Regions in this strategic construct possess some level of market power over returns to mobile factors. Let r denote endogenous returns to capital net of a source based unit tax τ. Profit maximizing mobile factor equilibrium conditions become,

$$r = F_K^i - \tau_i\,. \tag{11}$$

Firms view r as parametric. With IRS, not all factors are paid their marginal product (Boadway et al., 2004). Here, given the case of perfectly mobile capital, returns to capital become (using equations (2) and (11)),

---

[7] Inequalities in both example equations (7) and (9) hold for all relevant input combinations from equations (3) - (5).

$$(r+\tau)K = \alpha F(L,K,E) - F_L L - F_E E\,, \tag{12}$$

With perfect mobility, r must be equalized across regions in equilibrium. Equations (10) and (11) provide the necessary 3 x 3 system of equations required to determine equilibrium values of K_i and r as implicit functions of tax rates t , τ and pollution emissions E. The following is a summary of the relevant jurisdiction specific comparisons derived:

$$\frac{\mathrm{d}K}{\mathrm{d}t} = 0,\ \frac{\mathrm{d}K}{\mathrm{d}\tau} = \frac{1}{2F_{KK}} < 0,\ \frac{\mathrm{d}K}{\mathrm{d}E} = \frac{-F_{KE}}{2F_{KK}} > 0\,, \tag{13}$$

$$\frac{\mathrm{d}r}{\mathrm{d}t} = 0,\ \frac{\mathrm{d}r}{\mathrm{d}\tau} = -\frac{1}{2},\ \frac{\mathrm{d}r}{\mathrm{d}E} = \frac{f_{KE}}{2} > 0\,, \tag{14}$$

Irrefutable signs stemming from the maximization hypothesis apply to all comparisons. Higher capital tax rates deflect capital while increasing allowable emissions attracts capital. Similarly, returns to capital decline with higher capital tax rates and returns increase with increases in emissions allowances.

Output from production is consumed as a composite private good, C, or supplied to the regional government to produce a Samuelsonian public good, G. The public good is financed by taxing both the fixed factor and capital where,

$$G = tL + \tau K\,. \tag{15}$$

Taxing the fixed factor in this manner ensures the efficient provision of G (Kunce, 2000).

Regional consumption is defined,

$$C = \alpha F(L,K,E) - rK - G + r\eta\overline{K}\,, \tag{16}$$

which represents regional output − net of returns to capital, public good financing and adding back the region's capital ownership returns. Fixed, identical residents of a region receive utility from consumption and local public goods, but suffer disutility from the level of pollution emissions. Regional utility takes the form, $U(C,G,E)$, where U_C and $U_G > 0$, but $U_E < 0$. Higher E corresponds to poorer environmental quality where E represents a pure public bad. In keeping with the Arrow-Debreu (Wilson 1999) separation assumption for general equilibrium constructs, residents have two distinct roles in the model. First, as consumers, they seek to maximize utility over a bundle of goods and services. Second, supplying production inputs and in return receiving income returns. More of the mobile factor and lax environmental standards enhance local production and can provide residents with higher incomes hence more consumption. However, in order to attract the mobile factors, the jurisdiction lowers taxes (effecting G) and/or relaxes environmental regulations (lowering utility directly) thus setting up a characteristic economic tradeoff.

Will imperfect competition with IRS among jurisdictions lead to efficiency? Since all residents in the model are fixed and identical, we can reduce the analysis to a regional focus providing a useful benchmark. Social efficiency requires the maximization of a region's utility subject to (i) utility in all other jurisdictions is equalized to a fixed level, (ii) aggregate production and consumption clear, and (iii) the mobile factor stocks are allocated entirely among regions (clear). The resulting social optimum conditions are well known (see Oates 1988; Wilson 1996; Kunce 2022) therefore derivation discussion in this section is keep to a minimum. Ignoring any corner solutions, social efficiency becomes,

$$MRS_{G,C} = \frac{U_G}{U_C} = 1 \quad \forall i, \tag{17}$$

$$MRS_{E,C} = \frac{-U_E}{U_C} = \alpha F_E \quad \forall i. \tag{18}$$

Equation (17) represents the familiar 'Samuelson condition' for the provision of public goods (Wilson 1996). This appropriate optimality condition suggests that the marginal rate of substitution ($MRS_{G,C}$) between the public good and consumption (over all regional residents) equals the marginal cost of providing an incremental increase in the public good. Given equations (15) and (16), the marginal rate of transformation in this context is one for one. Equation (18) shows that regions should choose a combination of environmental quality and consumption such that the marginal rate of substitution between the two equals the increment in output associated with a marginal change in allowed emissions (recall that $U_E < 0$). Equation (18) represents a pseudo Samuelson rule for environmental quality. Recall, α is viewed as parametric by Nash players.[8]

Regional governments play a Cournot-Nash game in tax rates and pollution standards. Acting as benevolent dictators, authorities in each region will choose $\theta = \{t, \tau, E\}$ that maximize the common utility of its residents, subject to holding these policies in the other region as given. A region's utility maximizing conditions become,

$$\frac{\partial U}{\partial \theta} = U_C \frac{\partial C}{\partial \theta} + U_G \frac{\partial G}{\partial \theta} + U_E \frac{\partial E}{\partial \theta} = 0, \tag{19}$$

---

[8] Alternatively, given production with a scalar constant, $\alpha F(L, K, E)$, the marginal product with respect to emissions becomes $\alpha F_E(L, K, E) = \alpha F_E$. Conventional models prescribe F_E.

where using equations (14) and (15),

$$\frac{\partial C}{\partial \theta} = \alpha\left(F_L \frac{\partial L}{\partial \theta} + F_K \frac{\partial K}{\partial \theta} + F_E \frac{\partial E}{\partial \theta} \right) - (r \frac{\partial K}{\partial \theta} + K \frac{\partial r}{\partial \theta}) - \frac{\partial G}{\partial \theta} + \eta \overline{K} \frac{\partial r}{\partial \theta}, \qquad (20)$$

and,

$$\frac{\partial G}{\partial \theta} = t \frac{\partial L}{\partial \theta} + L \frac{\partial t}{\partial \theta} + \tau \frac{\partial K}{\partial \theta} + K \frac{\partial \tau}{\partial \theta}. \qquad (21)$$

Recall that L is fixed and best response (reaction) functions are derived by evaluating equations (19) - (21) with respect to each choice variable where,

$$(t): \quad U_C \frac{\partial C}{\partial t} + U_G \frac{\partial G}{\partial t} + U_E \frac{\partial E}{\partial t} = 0, \text{ with } \frac{\partial E}{\partial t} = 0, \qquad (22)$$

and,

$$\frac{\partial C}{\partial t} = \alpha F_K \frac{\partial K}{\partial t} - r \frac{\partial K}{\partial t} - K \frac{\partial r}{\partial t} - \frac{\partial G}{\partial t} + \eta \overline{K} \frac{\partial r}{\partial t},$$

$$\frac{\partial G}{\partial t} = L \frac{\partial t}{\partial t} + \tau \frac{\partial K}{\partial t}. \qquad (23)$$

Evaluating equations (22) and (23) at the symmetric equilibrium where η = 1/2 resulting in $\eta \overline{K} = K$ and using equation (11) yields,

$$(t): \ U_C\left((\alpha - 1) F_K \frac{\partial K}{\partial t} - L \right) + U_G\left(L + \tau \frac{\partial K}{\partial t} \right) = 0. \qquad (24)$$

To complete the best response function with respect to t, we substitute into equation (24) the relevant comparison from equations (13) resulting in,

$$(t): \quad \frac{U_G}{U_C} - 1 = 0. \qquad (25)$$

Following the same derivation procedure, best response functions for τ and E become,

$$(\tau): \quad \frac{U_G}{U_C}\left(\tau \frac{1}{2F_{KK}} + K\right) + (\alpha - 1)F_K \frac{1}{2F_{KK}} - K = 0, \tag{26}$$

$$(E): \quad \frac{U_G}{U_C}\left(\tau \frac{-F_{KE}}{2F_{KK}}\right) + \frac{U_E}{U_C} + (\alpha - 1)F_K \frac{-F_{KE}}{2F_{KK}} + \alpha F_E = 0. \tag{27}$$

Solving equations (25) - (27) simultaneously yields,

$$\tau = -(\alpha - 1)F_K, \tag{28}$$

$$\frac{U_G}{U_C} = 1, \tag{29}$$

$$\frac{-U_E}{U_C} = \alpha F_E + \frac{(\alpha - 1)F_K F_{KE}}{2F_{KK}}, \tag{30}$$

where the far right term in equation (30), using equation (28), can be rewritten as,

$$\tau\left(\frac{-F_{KE}}{2F_{KK}}\right). \tag{31}$$

Recall the bracketed term in equation (31) reflects the movement of capital with respect to changes in emission allowances (see equation 13). The optimal result in equation (29) reflects the efficient provision of public goods. Allowing regions access to free-to-vary fixed factor taxation ensures this outcome. Equation (28) shows that symmetric regions choose a capital tax rate of zero under CRS and subsidize capital, directly related to capital's marginal product, with IRS. These two conditions are analogous to Result 2 in Burbidge and Cuff (2005). The marginal return to capital in a region may be different than what firms pay to employ the capital input. Burbidge-Cuff concluded that each symmetric region uses a capital subsidy to correct this production externality induced by IRS.

Regarding environmental standards, the far right term in equation (30), rewritten in equation (31), represents the wedge between decentralized and social efficiency. Under CRS, this term vanishes ($\alpha = 1, \tau = 0$). If this wedge term is positive (negative) regions set allowed emissions higher (lower) than the social optimum. Here, the social benefit from improving the environment is less than the social cost with capital subsidies. The wedge is negative driven by τ, therefore, allowed emissions are set lower than the social optimum. The source of this inefficiency is the Oates-

Schwab fiscal effect[9] of environmental policy, regions tighten standards to the point that willingness to sacrifice consumption equals the incremental output effect caused by a change in emissions allowances plus the accompanying tax revenue effects. Subsidizing capital under IRS reduces incentives to chase this input with relaxed environmental policy. Nash players act as if they do not fear capital flight with respect to stricter environmental policy. In the next section we explore best response functions when regions do not have access to first-best taxation (Wilson, 1999).

3. Capital taxation alone

In this second-best setting, fixed factor taxes are now zero and the government's budget constraint becomes,

$$G = \tau K, \tag{32}$$

where,

$$\frac{\partial G}{\partial \theta} = \tau \frac{\partial K}{\partial \theta} + K \frac{\partial \tau}{\partial \theta}, \quad \theta = \{\tau, E\}. \tag{33}$$

Best response functions for τ and E are equivalent to equations (26) and (27). Solving these response functions simultaneously yields the optimal conditions,

$$\tau = -\frac{\left((\alpha - 1)F_K + 2F_{KK}K(MRS_{G,C} - 1)\right)}{MRS_{G,C}}, \tag{34}$$

$$MRS_{E,C} = \alpha F_E + \frac{F_{KE}\left((\alpha - 1)F_K + 4F_{KK}K(MRS_{G,C} - 1)\right)}{2F_{KK}}. \tag{35}$$

A meaningful (interior) solution requires a positive capital tax, τ. This forces the numerator in equation (34) to hold a negative sign. A negative numerator requires the underprovision of public goods, $MRS_{G,C} > 1$, and the marginal product of capital term, $(\alpha - 1)F_K$, to be sufficiently small.

Taxing only mobile capital, generally, leads to the well received underprovision of public goods outcome (Wilson, 1986; Zodrow and Miezkowski, 1986). Because jurisdictions finance a unit increase in public goods with an increase in the capital tax, capital will flee in response to the tax increase (see equations (13)). Therefore, the marginal cost of a unit increase in the public good includes not only the direct resource cost but also the loss in tax revenues due to capital flight. The loss of local tax revenue is not viewed as a social cost because other jurisdictions realize a fiscal

---

[9] See Oates and Schwab (1988) equation 9, p. 343. Equation (31) herein is analogous.

benefit from the inflow of capital. The cost of local public goods is then overestimated by the jurisdiction which will choose an inefficiently low level of public goods (Wilson, 1999). An interior solution requires G to be positive, no corner solutions. Imagine a two-good world with G on the horizontal axis. Optimality requires a tangency where the marginal rate of subsitution, $MRS_{G,C}$, equals the marginal rate of transformation, dC/dG. Under-provision of G is an intersection moving to the left of tangency on the horizontal axis. This intersection occurs where $MRS_{G,C} > dC/dG$, or $MRS_{G,C} > 1$ herein. Under-provision of G is a necessary condition for the numerator of equation (34) to be negative.

What level of environmental quality should be set in order to maximize jurisdictional utility? A positive capital tax rate implies that the numerator in the far right term of equation (35) is also negative (recall $F_{KE} > 0$). The marginal rate of substitution between allowed emissions and consumption now exceeds the social cost, αF_E. Consequently, regions will allow pollution emissions beyond the socially efficient level in order to lure mobile capital in the pursuit of more consumption and tax revenues. The determination of emission levels and the tax rate on capital are closely interrelated. If the tax rate on capital is not zero, clearly the social benefit from improving the environment will not equal the incremental output associated with allowed emissions. Nash equilibria are dependent on the level of efficiency in public good provision.

Interestingly, equation (35) provides a means to examine how varying α impacts the magnitude of distortions from social efficiency. In order to see a clear picture, it is useful to consider a specific numerically simulated case. Again, the terms to the right of αF_E in equation (35) represent the wedge between decentralized and social environmental efficiency. The impacts of varying α above unity, can be simulated using a constant elasticity of substitution (CES) production function of the basic form, $F = L^{(1/3)\alpha}K^{(1/3)\alpha}E^{(1/3)\alpha}$, where the elasticity of substitution is equal to one.[10] Equal input levels and exponents avoid any efficiency distortions stemming from input intensities. Changes in α are modeled in simple percentage increases (e.g., 1%, 3%, 6%) above one. The 'wedge' referred to above will be captured by the percentage difference from social efficiency, αF_E. Percentage (proportional) changes are presented instead of raw numerical results because actual simulated values are relatively meaningless in this context. First-best simulations presume $MRS_{G,C} = 1$. In addition, two levels of public goods underprovision are considered, 5% and 10% above unity.[11] Table 1 presents the simulated outcomes.[12]

---

[10] See the appendix to this paper for the derivation of F.

[11] Positive capital tax rates drive the underprovision levels.

[12] Simulations were conducted with Mathematica version 12.1.

Table 1: **Simulation Results**

First-Best. $MRS_{G,C} = 1$	
Percent (Δ *α*)	**Percent from αF_E**
1.0	-0.3
3.0	-0.8
6.0	-1.6
Second-Best. $MRS_{G,C} = 1.05$	
Percent (Δ *α*)	**Percent from αF_E**
1.0	3.1
3.0	2.6
6.0	1.8
Second-Best. $MRS_{G,C} = 1.10$	
Percent (Δ *α*)	**Percent from αF_E**
1.0	6.4
3.0	5.9
6.0	5.1

Rising IRS certainly affect the proportional magnitudes of potential distortions in devolved environmental policy but what Table 1 illuminates is that the inefficiency of public goods provision has a more pronounced impact. Jurisdictions that lack the availability of first-best fiscal tools appear more likely to engage in destructive environmental practices.

4. Concluding remarks

Even within the best-case for decentralized decisions regarding environmental policy, localized pollution, there exists a large body of literature arguing that devolved choice results in suboptimal outcomes (Oates, 2002). Local governments will lower standards in order to reduce compliance costs for existing and prospective firms. Evidence of a broad environmental race-to-the-bottom, however, is scant (Willardsen, 2021; Wilson, 1996). Theoretical models that produce this outcome rely on modeling assumptions that may not resemble the realities they profess to describe. Herein, we relax one such assumption, aggregate CRS. With IRS, symmetric regions in a Nash equilibrium subsidize capital and do not use the environment as a policy lever. What appears to reoccur in the theory, however, is the importance of the constraints on access to tax instruments. Second-best fiscal structures hold local governments hostage and provide incentives to use environmental policy to sway capital movement. Alternatively, first-best modeling either produces efficient equilibria or outcomes where either the direction or magnitude of the distortions are favored or not that severe (Wilson, 2015).

References

[1] Dijkstra, B. and Fredriksson, P. (2010). Regulatory environmental federalism. Annual Review of Resource Economics, 2, pp. 319-339.

[2] Holzinger, K. and Sommerer, T. (2011). 'Race to the bottom' or 'race to Brussels'? Environmental competition in Europe. Journal of Common Market Studies, 49, pp. 315-339.

[3] Costa-Font, J., De-Albuquerque, F. and Doucouliagos, H. (2015). Does inter-jurisdictional competition engender a "race to the bottom"? A meta-regression analysis. Economics and Policy, 27(3), pp. 488-508.

[4] Chirinko, R. and Wilson, D. (2017). Tax competition among U.S. states: Racing to the bottom or riding on a seesaw? Journal of Public Economics, 155, pp. 147-163.

[5] Perälä, M.J. (2008). Increasing returns in the aggregate: Fact or fiction? Journal of Economic Studies, 35(2), pp. 112-153.

[6] Burbidge, J. and Cuff, K. (2005). Capital tax competition and returns to scale. Regional Science and Urban Economics, 35(4), pp. 353-373.

[7] Oates, W. (2002). A reconsideration of environmental federalism, in Recent Advances in Environmental Economics, Eds: J. A. List and A. de Zeeuw, Edward Elgar Publishing: UK, pp. 1-32.

[8] Oates, W. and Schwab, R. (1988). Economic competition among jurisdictions: Efficeincy enhancing or distortion inducing. Journal of Public Economics, 35, pp. 333-354.

[9] Cropper, M. and Oates, W. (1992). Environmental economics: A survey. Journal of Economic Literature, 30, pp. 675-740.

[10] Kunce, M. and Shogren, J. (2005). On interjurisdictional competition and environmental federalism. Journal of Environmental Economics and Management, 50, pp. 212-224.

[11] Wyoming Oil and Gas Conservation Commission (WOGCC) (2023). https://wogcc.wyo.gov

[12] Kunce, M. (2022). Decentralized environmental regulation with agglomeration forces. Business and Entrepreneurship Journal, 11(1), pp. 27-36.

[13] Boadway, R., Cuff, K. and Marceau, N. (2004). Agglomeration effects and the competition for firms. International Tax and Public Finance, 11(5), pp. 623-645.

[14] Kunce, M. (2000). A Nash tax game extending the generality of the Henry George Theorem. Economics Letters, 66, pp. 229-233.

[15] Wilson, J. (1999). Theories of tax competition. National Tax Journal, 52, pp. 269-304.

[16] Wilson, J. (1996). Capital mobility and environmental standards: Is there a theoretical basis for a race to the bottom? in Fair Trade and Harmonization, Vol. 1, eds. J. Bhagwati and R. Hudec. MIT Press, pp. 395-427.

[17] Wilson, J. (1986). A theory of interregional tax competition. Journal of Urban Economics, 19, pp. 296-315.

[18] Zodrow, G. and Miezkowski, P. (1986). Pigou, Tiebout, property taxation and the under-provision of local public goods. Journal of Urban Economics, 19, pp. 296- 315.
[19] Willardsen, K. (2021). Measuring fiscal interactions in local federalism. Papers in Regional Science, 100(4), pp. 891-923.
[20] Wilson, J. (2015). Tax competition in a federal setting, in Handbook of Multilevel Finance, eds. E. Ahmad and G. Brosio. Edward Elgar Publishing, pp. 264-290.

Appendix

A.1. Derivation of the simulation production function

The many input CES production function takes the general form,

$$F = \left[\sum_i \pi_i x_i^{\rho}\right]^{\frac{\alpha}{\rho}} \text{ and } \sum_i \pi_i = 1, \tag{A1}$$

where i is the index for the number of inputs, π represents the input factor relative weights, x represents the production inputs, ρ is related to the elasticity of substitution of factors, σ, where $\sigma = \frac{1}{1-\rho}$ and varies between 0 and infinity, and lastly α represents the degree of homogeneity as shown in the text above, where $\alpha \geq 1$. In our case, equation (A1) becomes,

$$F = \left[\pi_1 L^{\rho} + \pi_2 K^{\rho} + \pi_3 E^{\rho}\right]^{\frac{\alpha}{\rho}}, \tag{A2}$$

with the input weights equal to 1/3 each. We presume the elasticity of substitution equals unity everywhere, thus $\sigma = 1$ which forces ρ to be zero. This is problematic because F becomes indeterminate, $1^{\alpha/0}$. Consider the natural logarithm of both sides of equation (A2),

$$\ln F = \ln\left[\tfrac{1}{3} L^{\rho} + \tfrac{1}{3} K^{\rho} + \tfrac{1}{3} E^{\rho}\right]^{\frac{\alpha}{\rho}} = \frac{\alpha \ln\left[\tfrac{1}{3} L^{\rho} + \tfrac{1}{3} K^{\rho} + \tfrac{1}{3} E^{\rho}\right]}{\rho}, \tag{A3}$$

where the numerator, $num(\rho)$, and the denominator, $den(\rho)$, both tend to zero as $\rho \to 0$. If the ratio $num'(\rho)/den'(\rho)$ exists then using L'Hôpital's rule,

$$\lim_{\rho \to 0} \frac{num(\rho)}{den(\rho)} = \lim_{\rho \to 0} \frac{num'(\rho)}{den'(\rho)}. \tag{A4}$$

Taking the derivative of the numerator[13] of equation (A3) with respect to ρ,

$$num'(\rho) = \frac{\alpha}{\left[\tfrac{1}{3} L^{\rho} + \tfrac{1}{3} K^{\rho} + \tfrac{1}{3} E^{\rho}\right]} \left[\tfrac{1}{3} L^{\rho} \ln L + \tfrac{1}{3} K^{\rho} \ln K + \tfrac{1}{3} E^{\rho} \ln E\right], \tag{A5}$$

then finding the limit,

---

[13] Recall, if $y = x^{\rho}$, $dy/d\rho = x^{\rho} \ln x$.

$$\lim_{\rho \to 0} num'(\rho) = \frac{\alpha}{[1]}\left[\tfrac{1}{3}\ln L + \tfrac{1}{3}\ln K + \tfrac{1}{3}\ln E\right] = \left[\alpha\,\tfrac{1}{3}\ln L + \alpha\,\tfrac{1}{3}\ln K + \alpha\,\tfrac{1}{3}\ln E\right] =$$
$$\ln L^{\alpha(1/3)} K^{\alpha(1/3)} E^{\alpha(1/3)} . \qquad \text{(A6)}$$

Taking the derivative of the denominator of equation (A3) with respect to ρ,

$$den'(\rho) = 1,$$
$$\lim_{\rho \to 0} den'(\rho) = 1 , \qquad \text{(A7)}$$

therefore as $\rho \to 0$,

$$\ln F = \ln L^{\alpha(1/3)} K^{\alpha(1/3)} E^{\alpha(1/3)} , \qquad \text{(A8)}$$

where the inverse ($e^{\ln x} = x$) of equation (A8) is equivalent to the CES production function used in section 2 of the text.