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International Competition and Real Wages: The Role of Public Infrastructure and Environmental Policy

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Abstract

Based on a form of Bergmann crowding or occupational exclusion model, in this paper we consider the role of infrastructure and environmental policy as they shape the productivity of trading partners that are both or all active in the same industry. The industry is subject to traditional technology change as a factor shaping the competitive productivity position of one country relative to another as defined by traditional measures of inputs, shaping costs to the firm and its near supply chain (c) and output. Productivity is also shaped by companion infrastructure (i) and environmental factors (d). Based on augmented productivity measures to include the effect of these public inputs leads to what may be termed full productivity of individual firms in the production of traditional economic goods and services. When one country improves its full productivity relative to others real wages or GDP of the world economy rises, but the improving country realizes more than 100 percent of the global wage gains. The discussion includes public environmental elements (p) which can serve as a beneficial infrastructural factor (i) or can be in the form of what can be called disamenties (d) such as environmental damage from pollution of air or water or deterioration of aesthetic features. Each of these can enhance full productivity of traditionally measured output of the firms or an economy. The effects of the factors (c), (i) and (d) can be local, regional or global. To illustrate, water pollution may increase full productivity of an industry and show up as good economic performance but may have local adverse impacts as well as unmeasured regional and hemispheric or global non-market costs, reducing overall well-being. We offer this work in honor of our friend George Johnson. We thank William J. Baumol and Paul A. Samuelson for encouraging work augmenting such international competition research and related applications such as occupational crowding and to a reviewer of an earlier draft for valuable suggestions.

Keywords

International Trade, Environment, Sustainability

1. Introduction

A firm's productivity can be shaped by many elements, ranging from quality of non-labor inputs, labor skills, and managerial talent internal to the firm. Yet external factors can be important and subject to modification by industrial policy decisions beyond the firm. In this paper, we illustrate the role of two broad external factors. One broad category is public infrastructure shared by others which may operate locally, regionally or globally. Another broad category is what we refer to as disamenities[1]. These can be realized via using the environment to dispose of undesirable byproducts of production activity such as with air or water pollution inducing aesthetic and health effects[2] with disfigurement of the landscape or water resources. On the other side environmental amenities can be a central input to other industries and healthful inspiration. The productivity element and the external elements can operate locally, regionally, or globally.

These factors can be used separately or even in opposition. And the choice is often shaped by national and internation forces—as well as by local communities. A city may wish to promote tourism trade and may devote its own or external resources to enhance shoreline resources and at the same time utilize sewerage disposal into a waterway, lake, or ocean[3]. Or may have an sustainability infrastructure project which restores a watershed damaged in prior years to promote a replacement industry (such as tourism)[4] by others. Both the creation of infrastructure or allowing environmental damages can, ironically, both be thought of as external factors favorably affecting private productivity, depending on the setting. Much of environmental technological, infrastructural factors play out in competition or advantage *within* a country or connected regions such as across U.S. states or across the Nordic Countries[5]. Yet much of it plays out among various countries or groups of *competing* countries. We argue that international competition can accentuate the incentives to shape productivity in chosen industries.

[1]The opposite, environmental *amenities* may be central to other alternative industries, such as real estate or tourism.

[2]The National Library of Medicine (NIH) has reported extensively on the issues of Methymercury contamination (Krabbenhoft, 2004)

[3]Miami and nearby communities have traditionally and even today disposed of sewerage and runoff water directly into the Atlantic and likely into the Gulfstream.

[4]In the movie directed by Robert Redford, "And a River Runs Through It," Missoula and the Blackfoot and Clark Fork are the idealized setting. Another element is the inspirational aspect of natural beauty as championed by John Muir.

[5]In 1969 both the Rouge River in Detroit and the Cuyahoga River in Cleveland caught on fire from industrial pollution. Was this a coincidence or a possible example of within country industrial competition between Michigan and Ohio? In 2019 there was a 50th year celebration of the work done over the years to restore the Rouge.

In one case, infrastructural related amenities can enhance the environment and health, providing an added boost to well-being beyond a country's real wage or traditional GDP measures. In other cases, GDP gains may come at the cost of various health and environmental disamenities. Positive affect and health aspects—not included in GDP measures—could be an added boost to a more comprehensive measure of well-being as suggested by time use studies (Hamermesh, 2023; Juster & Staford, 1985).

Conceptually, within a country or a set of countries with labor mobility, people can move to "arbitrage" wage differentials. In the theory of international trade a common but unstated assumption is that the labor force cannot simply move freely to the most favored labor market. In this paper we work with the simplifying and relatively plausible assumption of limited cross border mobility (Krugman, 1979; Singhal et al., 2025). Ricardo did not assume that vineyard workers in Portugal would move to England and produce textiles. Or that people would move from London to tend the vineyards in Portugal. And we do not either.

For this cross-country setting wages can persistently differ based on persistent differentials in a country's firm level technology as well as infrastructural or environmental disamenities which combine to condition augmented or full firm level productivity. In the conceptual framework applied here with two or more countries active in the same industry, the country that boosts its productivity relative to the other(s) will also boost global wages based on traditional wage or GDP measures but will realize more than 100 percent of the worldwide gains. That is, the other country or countries will experience a real wage decline.

In section 2, we review briefly the concept of crowding and also the concept of public infrastructure in improving productivity. The same approach is used to highlight the role of environmental disamenities. In Section 3, we identify a wide range of simple general equilibrium models all supporting our approach and suggesting that the perspective has a robust conceptual footing. Section 4 considers specific examples of the ideas based on the complex hydrology of methyl mercury. This highlights the central role of understanding the structure of the underlying environment to assess the likely outcomes of different uses. Section 5 concludes.

2. Economic Literature and Background

The idea of labor market crowding was set out by Bergmann in 1986. In contrast to the often-used assumption of homogeneous human capital, occupations are separate types of human capital—often with little substitution. Her idea was that women, being excluded from a wide range of occupations, would experience what here is interpreted as a reduced domain of economic activity as is well documented (Goldin, 1990). This effect of this reduced domain is to lower wages from the "oversupply" of labor. And the men, here in general equilibrium, are seen as supplying some of their labor to the jobs women would have had otherwise taken—extending their domain of activity. By reducing the supply of men in men's jobs their wages rise. A parallel theoretical result occurs when one labor

group, such as via skilled labor and management teams using information technology (aka AI?), realizes skill *extensive* technology gains (Johnson & Stafford, 1998).

Both men and women can act in a form of *self-exclusion*-from certain occupations, possibly because it does not match their social identity (Tajfel & Tutner, 1979) or self-perception (Steele, 1988), thereby reducing their domain of activity (Anaya et al., 2002). Men, displaced from their father's production jobs crowded into traditional men's jobs', likely adding to wage woes there (Li & Stafford, 2017).

In the open economy context, infrastructure, i, as a productivity factor external to the firm and within a country's industry in which they trade, can similarly play an important crowding role on their trading partners (Stafford, 1988). One question is how empirically important may a given form of infrastructure be? Cost benefit studies of the payoff to specific infrastructure projects are challenging because of the potentially diverse set of beneficiaries and the hard to measure costs, including environmental disamenities such as the alteration of natural landscapes. Another approach has been in work with aggregate time series data. There the evidence suggests strong impacts of public infrastructure. Notably, do certain forms of public expenditure have a productivity payoff? There is a strong apparent payoff to public capital, especially "core" infrastructure. Nonmilitary expenditures, such as on "streets, highways, airports, mass transit, sewers and water systems, have the most explanatory power for productivity" (Aschauer, 1989).

A concern is the question of desired selectivity in what projects are chosen. Mass transit is usually for particularly well-chosen settings resulting in a selected sample, and the payoff to projects in other settings can be more questionable. A dam may provide valuable infrastructure until it breaks. Obviously, the projects not chosen and others would not generally have as good a payoff. For Holland to compete with alpine skiing in Switzerland they would have to "move mountains"!

Examples of environmental disamenities. d, to boost a firm's output are abundant. Use of lakes and rivers as disposal sites from bygone eras may have diminished some, but there are numerous global examples today such as in the chase for "rare earths". While traditional pollution is of air, water and land, the concept is broad. For a somewhat extreme example, suppose a firm places unsightly billboards in the trading partner's towns as a way to boost "full" productivity, including a reduction in information cost to foreign buyers.

The firm's cost will be related to the productive technology available to it and its immediate suppliers, c. Historically, access to the product's features and the underlying production were subject to reverse engineering of the product and by diverse ways of learning how to produce it, such as by inviting an outpost facility from the trading partner's industry (Johnson & Stafford, 1997). Now it is possible and can even be rather easy to see the design of the product with code from computer aided design (CAD) and how to get the robots to march via computer assisted manufacturing (CAM). Further, some advanced technologies (Chen &

Stafford, 1986)[6] have recently and promptly diffused globally and been more closely connected to tradable goods, including grading of hardwood flooring or vegetable sorting, for example. This diffusion of technology within a country can lead to a more important role AI, as an element of information technology, can be seen as accelerating the impacts of global technological change and diffusion—displacing and crowding workers away from a wide range of occupations, as the technology induces skill *extensive* technological change—as distinct from skill *intensive* technical change within a given line of employment or country. (Eliasson, 1987; Johnson & Stafford, 1998; Bound & Johnson, 1992; Kim & Stafford, 1999).

3. Modelling Competing Trading Partners

Consider an algebraic two-country model[7] with 3 tradeable goods (or services—such as tourism as an exportable). In each country there are 3 possible industries, A, B and C Good A is the specialty of Country 1 throughout and Good C is the specialty of Country 2 throughout. Unlike the traditional Ricardo model where there are no shared industries or technical charge (here just A and C with unchanging technology), here, initially, good B is only produced by Country 1. Over time and through productivity improvement in B in country 2 via c, i, and d, they become active in industry B. having import substitution and potentially then becoming a net exporter.

Here,

c is a productivity shaping component of the firm and its immediate suppliers which expresses a private good or usual relation between a unit of labor and the output of the firm,

i is external to the firm (non-purchased) within-country public infrastructure external to the firm which additionally strengthens the relation between unit of labor and output of the firm and its immediate suppliers

d is a measure of environmental (or public) disamenities[8] external to the firm, including factors such as pollution or diminished aesthetic properties of the environment.

λ (with subscripts for the country and industry) is the "full" productivity based on both the private productivity elements in c and public elements, i and d. Here we have the combined effects of the more traditional variety, c, and public inputs i and d, summarized in a single combined productivity index.

Under common simplifying assumptions for simple general equilibrium models, the real wages, *W*, in the two countries when both are active or competing in

[6]This was based on a study of a visionary company in Ann Arbor named Machine Vision International. Its program was based on morphology and color differentials. Its ideas are now used globally and in diverse processing systems, but the firm went into bankruptcy likely for being too much ahead of the times.

[7]In the context of the labor market think of men and women and the three "industries" as housework business/office work and STEM work (Anaya et al. 2022; Li & Stafford, 2017). The mothers of current mid career women are often reported to have been housewives.

[8]Or, as noted above, complementary amenities—as in the case of tourism.

B (W_1 and W_2) from Equation (2) (Johnson & Stafford, 1993) are:

$$W_1 = \lambda_A^{\infty}\lambda_{B1}^{\beta+\gamma}\lambda_{B2}^{-\gamma}\lambda_C^{\gamma}$$

$$W_2 = \lambda_A^{\infty}\lambda_{B1}^{-\alpha}\lambda_{B2}^{\alpha+\beta}\lambda_C^{\gamma}$$

Here the full productivity is λ = λ(c, i, d) and ∂λ/∂m > 0 for m = c, i, d and α. β, γ are expenditure shares adding to 1.

Notably, the real wage in Country 1 has an inverse relation to improvements in the full productivity (λ) in industry B in country 2. Conversely, given a productivity level in Country 2 for industry B, improvement in productivity in Country 1 boosts its real wage. If either country improves in its respective specialty industry—A or C (tourism and agriculture?) both countries realize added gains from trade (just as in a Ricardo "separate spheres" case)[9].

This type of model of technological competition is, for economic models, remarkably robust. For example, adding non-traded goods just damps the trade connection. Considering a multicounty setting, a small country fits, and it will see benefits from its position in B relative to the weighted average of all others. In the approach here we apply Occam's Razor and keep it a simple general equilibrium model by not including the cost of altering the λ values[10]. For disamenities (d) the assumption is that apart from the diffuse environmental costs the direct costs are modest[11]. For productive technology there is the issue of differential cost of creating versus adopting technology. In the case of the internet there are both private technology (c) and infrastructural (i) elements, and the initial concept costs were modest[12]. Other infrastructure such as expensive dams for low-cost electricity or ports have complex cost-benefit issues, yet some projects—such as maintaining beaches for tourists (and locals) by removing red tide may have low "out-of pocket" costs.

Different simple modelling choices show the same main result in a trade setting. This works for a two-country geometric representation (Hymans & Stafford, 1995). Another modeling choice with the same message, based on linear programming, produces similar results (Gomery, 1994; Gomery & Baumol, 1997; 2000). And another variant with a headquarters perspective shows similar results (Johnson & Stafford, 1997). Why is the result robust? One interpretation comes from a crowding perspective (Bergmann, 1986; Goldin, 1990; Johnson & Stafford, 1998; Anaya et al., 2022). Assume Country 1 has workers displaced from B by Country 2 (and vice versa for Country 1 if they can offset by recovering their initial lead in B) into their respective specialty. This lowers the price of their stable export and

[9]The internet could boost one country's productivity relative the others in industry B. One the other hand, suppose it led to improved productivity in *both* industry A and industry B?

[10]Sometimes the parsimonious perspective in modelling is termed reductionist. In contrast, for the discussion in Section IV of the hydrological example of methyl mercury diffusion, it seems that Hickam's dictum is more applicable!

[11]For example, the cost of the smokestack for atmospheric disposal or a pipe for sewage into the ocean or river is modest. Yet sewage can promote the spread of norovirus in oysters.

[12]There were modest costs to individual researchers and to establish the prototype Merit System by the National Science Foundation.

benefits Country 2 (an importer) in this way—who now also gets Good B at a lower price). Less labor now is now used in Country 2 for their specialty good. As a combined effect Country 1 experiences declining terms of trade[13].

4. Rivers, Lakes, Oceans and Hemispheres

Here we briefly consider mercury cycling in the context of competing environmental uses. Although mercury is a naturally occurring element, human activities have substantially increased its flux through the environment. Point source pollution can be problematic, but at most locations the primary source of labile mercury is via the atmosphere. Atmospheric mercury associated with particulates is deposited at local and regional scales while mercury gas has a longer atmospheric residence time, rendering it prone to hemispheric, and to a lesser degree, global distribution. Once inorganic mercury enters into waterways it can be microbially transformed into more toxic methyl mercury (MM) (Selin, 2009).

MM biomagnifies in aquatic food chains and can reach levels of concern, particularly for human and wildlife consumers of fish (Stafford & Haines, 1997). Like other biomagnified pollutants that travel through the atmosphere (including PCBs and PFAS), mercury is widespread and difficult to remediate on site. MM is always a disamenity as it serves no biological need and even at low levels can induce neurological damage as shown in NIH studies (Krabbenhoft & David, 2004). In contrast, to illustrate, at modest levels selenium is healthful but at higher levels it is not[14].

The complex and wide spread cycling of mercury implies that its disamenities can be local, regional or global and diverse in their impacts. Even within a species, fish MM concentrations can vary substantially among nearby lakes owing to numerous abiotic and biotic factors (Stafford & Haines, 1997). For example, lakes with larger watersheds (relative to their surface area) are provided with more effective collectors of atmospheric mercury (Aqdam et al., 2024) while those with longer food chains create more steps for MM to biomagnify (Cabana et al., 1994). The multi-faceted nature of mercury contamination contrasts with some other pollution issues such as biological oxygen demand (BOD) in a river which can be described handily by the Phelps-Streeter model.

In the case of diffuse hemispheric impacts there are reduced incentives to control airborne mercury levels. This contrasts with control of "point source" pollution such as acid mine drainage—as when a formerly polluted river has reversed from disamenities to the basis for a positive infrastructure, supporting alternative activity. The environmental cycling of mercury provides an interesting setting because it can promote traditional industry productivity via d or via i and can have local regional or hemispheric effects via disposal cost savings. On the other side

[13]An extended model can have a heterogeneous labor force with the "export" of technology boosting the wage of a subgroup (Johnson & Stafford 1993, Equation (3)).

[14]Canadian officials have often restricted industrial disposal of selenium since it can lead to levels beyond healthful natural levels. It continues as a problem in various settings.

reducing mercury can have an amenity value for well-being[15]. Further, controlling mercury can be seen as a key infrastructure for the outdoor recreation industry (particularly fishing) which "exports" tourist services or, on the other hand, boosting other industrial activity and traditional wage and income measures via productivity effects.

5. Conclusion

Infrastructure (i) and disamenties (d)—or amenities—can increase the position of one trading partner relative to another. The effects can operate locally, regionally or hemispheric/globally as with shipping lanes (i) or airborne pollution (d) of a large geographic area. From a single country' perspective the most advantageous conditions for boosting its real wages, as traditionally defined, would be access to the best technology for c (to beg, borrow or buy the best ideas) and to create infrastructure which only benefits them. And to have full productivity enhancing pollution from disamenities which may be experienced globally or at least regionally rather than locally. Another interesting perspective is where the environment can serve as sustainable infrastructure or amenities for an alternative set of industries. Cleanup of a river previously used to support an industrial production process (d) could become key infrastructure (i) for international tourism. Another feature is where each country finds ways to improve productivity in its export specialty (A or C in the discussion above). World GDP rises and *both* countries experience wage gains. Note that in the crowding model for the labor market "global GDP" of men and women combined is reduced.

The environment can be enhanced and maintained for sustainability to promote an infrastructure supporting certain industries—such as with air and water quality as amenities promoting tourism and residential value. Yet the same environment can also serve as a setting where disamenities—such as air and water pollution can also boost an industry's position. In some settings water and air pollution can be reversed to enhance an alternative industry. For this to happen understanding the structure of the environment matters. While some recovery efforts can be implemented in a straightforward way others are more involved and complex in concept. In this paper we have focused on the case of methyl mercury pollution. Methyl mercury has several specific features to know about. In contrast to some chemicals (such as sulfonamide which at low levels is notably beneficial), no level is beneficial. Methyl mercury biomagnifies, posing health effects, potentially worldwide, when fish are consumed.

Given economic competition between industries within a country and between countries, aspects of the environment can play an important role in shaping what can be called full productivity of a firm. In the context of the international economy the wage gains from improved overall or "full" productivity, -including use

[15]Research at the London School of Economics demonstrated a real time affect value to pleasant park settings in the city using innovative time use methods. Related is the health benefit (UCLA Health, 2025).

of the environment as an input factor, operate in addition to the traditional concept of a firm's productivity. The real wages of a country can rise dramatically increasing its share of boosted world GDP while lowering the real wages of its competition. And potentially lowering overall global well-being.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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