Benefit-transfer and spatial equilibrium

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ABSTRACT: Compelling empirical evidence suggests that people move in response changes in pollution and that firms move in response to regulation. We investigate the problem of benefit estimation and transfer in the context of a simple model where firms and people can move in response to regulation and pollution. Including these margins of adjustment changes the problem of benefit-transfer. It requires the evaluation of policies that affect more than one region at a time. This suggests an important role for evaluation strategies based on easily observable indicators of local welfare like total population, real income net of real estate, or the use of elementary standardized models of spatial equilibrium.

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1. Introduction

I investigate the problem of evaluating a prospective environmental regulation in the following situation. First, the prospective regulation is 'large' in the sense that it may affect environmental quality over a wide area and the costs of production in many sectors. Second, the prospective regulation will be applied to different regions with different stringencies. Third, our evaluation must be made purely on the basis of existing studies of related regulations. This is intended to be an abstract description of the problem of using 'benefit-transfer' methods to evaluate the Clean Air Act (or its amendments) and this act will be the focus of analysis. With this said, the analysis should apply to other similarly large environmental regulations, like the Clean Water Act.

For the current purpose, the essential feature of the Clean Air Act is that it applies different stringencies of regulation to US counties on the basis of their initial pollution levels. More polluted counties are declared to be 'non-attainment counties' and are subject to more stringent regulation than less polluted 'attainment' counties. There is now a large body of empirical work evaluating the Clean Air Act. This literature establishes the following stylized facts. First, the clean air act has improved air quality in at least some parts of the country. Second, people value cleaner air and pay more for houses in places where air quality is better. Third, the clean air act has been costly for firms. While these costs have led them to reduce polluting activities in non-attainment regions, these reductions have been at least partly offset by increases in attainment regions.

These stylized facts (and common sense) suggest that responses to the Clean Ar Act reflect a spatial equilibrium process. More specifically, it appears that people trade off their willingness to accept air pollution against their willingness to pay for inelastically supplied locations in unpolluted counties while firms adjust the location and composition of their activities in complicated but intuitive ways in order to reduce their costs of regulatory compliance.

As we will see, benefit-transfer is principally interested in the problem of using estimates of the value of pollution obtained in one situation and applying them to other similar situations. The discussion above suggests that this exercise may be problematic in the case of large regulatory interventions. To the extent that large regulations have pervasive effects, simply understanding the way that people value a less polluted environment will not be enough information to allow an evaluation of the regulation. We also need to understand the other ways that people and firms respond to regulation.

The bulk of this paper is devoted the following three tasks. First, surveying of the literatures that describe benefit-transfer and responses to the Clean Air Act. Second, developing a stylized spatial model of pollution regulation. This model suggests the importance of understanding the way firms and people move in response to regulation and of understanding how regulation affects the supply of goods. The third main task of the paper is to describe two methods to evaluate large hypothetical regulations in the spirit of benefit-transfer. The first of these assumes an understanding of how similar realized regulations affect the distribution of population and of real income across locations. The second assumes estimates of the effect of similar large regulations on two location specific attributes, 'productivity' and 'amenities', and proposes evaluating the implications of hypothetical regulations using a tractable general equilibrium model developed in Desmet and Rossi-Hansberg (2013).

2. Literature

I here survey two strands of literature. The first relates the practice of benefit-transfer, and the second to the effects of the Clean Air Act.

Benefit-transfer

The problem of transferring benefit estimates from one situation to another is the subject of a sufficiently large academic literature that it has led to a handbook devoted entirely to the topic. In this handbook Johnston, Rolfe, Rosenberger, and Brouwer (2015) provide an introduction to benefit-transfer methods. The problem of benefit-transfer involves three distinct problems. The first involves estimating preference parameters in an environment where data is available. The second involves the adjustment of these parameters to an alternative, but hopefully similar problem, and the third involves using the adjusted information about preferences to calculate welfare.

To be a little more specific, consider a world consisting of two jurisdictions, A and B, indexed by x and suppose that we observe land rent, r, pollution, S and wages, w in jurisdiction A and only income in jurisdiction B. Further suppose that we are able to use our information about pollution and land rent from jurisdiction A to estimate a demand schedule for residential land in jurisdiction A,

$$r_A(w_A,S_A) = \alpha_0 + \alpha_a w_A + \alpha_2 S_A.$$

Transferring this estimated demand curve to jurisdiction B involves adjusting for the change in income, holding all else equal. Thus, we have

$$r_B(w_B, S_B) = \alpha_0 + \alpha_a w_B + \alpha_2 S_B.$$

One of the more influential papers evaluating the Clean Air Act, Chay and Greenstone (2005), estimates exactly such a demand curve.

It is probably worth noting how completely conventional this is in the current practice of economics. A foundational axiom of economics is that people behave in predictable ways, and so if we understand how they make a particular decision, we can make a good guess at how they will behave when presented with the same choice again. That is, what is here called 'benefit-transfer', in much of the rest of the economics literature is simply the practice of using structural parameters estimated in one context to analyze some other problem.

The second main step in benefit-transfer involves using the transferred structural parameters to estimate the welfare implications of some hypothetical intervention. More concretely, for example, to calculate the change in consumer's surplus that would result in a reduction of pollution from S_B^0 to S_B^1,

$$\Delta \mathrm{CS} = \int_{S_B^0}^{S_B^1} r_B(w_B, S_B) dS.$$

Indeed, this is the main example used in Johnston *et al.* (2015) to illustrate the method.

This process implicitly involves three important assumptions. The first is that the demand estimation in jurisdiction A is, in fact, recovering structural parameters. The second is that consumer surplus is a reasonable measure of welfare to use in this instance. The third is that the change in regulation that reduces pollution in jurisdiction B does not lead to other substantive changes in the economy.

Smith, Van Houtven, and Pattanayak (2002) investigate the first of these assumptions and consider the way that different techniques for estimating preferences can be fit into a logically consistent description of utility. The second is an old problem in economics, and one to which we will return later. The third assumption is subject of most of the economics literature investigating the Clean Air Act.

The effects of the Clean Air Act

I here survey evaluations of the Clean Air Act in flagship economics journals. This survey shows that this act affects producers as well as individuals, that the effects of the act are different in different locations, and that regulation leads to the relocation of firms.

The Clean Air Act appears to have affected firms through channels that are, at least in some cases, quite obscure. For example, the production of cement involves heating limestone to a high temperature to make a commodity that is difficult to transport. Thus, the cement industry tends to consist of relatively small regional markets, each served by a small number of firms, each of which operates a large furnace. These furnaces have been the subject of intensive regulation under the Clean Air Act. This appears to raise barriers to entry and leads to further concentration of market power in regional markets. This, in turn, leads to oligopoly profits for incumbent cement firms and, presumably, larger losses for consumers (Ryan, 2012).

In a similarly obscure example, Gollop and Roberts (1983) investigate the effects of the Clean Air Act regulation on thermal power generation plants. They find that regulation has decreased productivity growth in power generation by encouraging the use of old plants. This occurs because the Clean Air Act subjects such plants to a less stringent standard than new plants. Regulation has also retarded productivity growth in power generation by encouraging smaller plants. Since smaller plants are less efficient than larger ones, this also reduces the productivity of power generation.

The Clean Air Act has also affected firms in more predictable ways. For example, in a paper that is particularly important for my analysis, Becker and Henderson (2000) investigate the way that firm births in pollution intensive sectors differ across Clean Air Act attainment and non-attainment counties. They find a much higher 'birth rate' for firms in pollution intensive industries in attainment counties. The Clean Air Act also calls for less stringent regulation of small firms. Not surprisingly, Becker and Henderson (2000) also find that polluting industries increasingly consist of smaller firms. Greenstone (2002) looks at all manufacturing firms and finds that non-attainment counties lost employment relative to attainment counties. Walker (2013) investigates the effect of the Clean Air Act on workers employed at regulated firms and finds that these workers are more likely to be unemployed and have lower earnings than workers in unregulated industries.

Interestingly, not all intuitively plausible margins of adjustment are economically important. Greenstone (2003) looks at the extent to which regulation under the Clean Air Act leads firms to emit more pollutants into other media and finds no evidence for this effect.

The literature also provides estimates of the benefits of pollution reductions caused by the Clean Air Act. Chay and Greenstone (2005) is a landmark example. In this exercise, the authors compare the change in housing prices between 1970 and 1980 for houses in non-attainment counties to attainment counties. This comparison leads the authors to conclude that a 1% decrease in county level TSP caused by the Clean Air Act will lead to between a 0.2 and 0.35% increase in the county's house prices. This suggests that people assign a large value to cleaner air.

3. A simple spatial model of environmental regulation

The literature survey above suggests the following stylized facts about spatially differentiated pollution regulation,

1. Firms may move from more to less regulated jurisdictions in order to avoid regulation.

2. People will pay more for housing in less polluted places.

In what follows I develop a model which reflects these two facts and then use this model to illustrate the issues that arise in transferring information about the value of pollution in one environment to another for the purpose of evaluating spatially differentiated pollution regulation.

The development of this model is intended to evaluate the following conjecture: *benefit-transfer allows us to measure the welfare implications of large, spatially differentiated pollution regulations under conditions (1) and (2) above*.

My intention is to demonstrate that in a world where regulation has important implications for firm behavior and location, simply looking at the way consumers value pollution is unlikely to lead to an understanding of the welfare implications of regulation. That is, the model is in the spirit of a counter-example to the conjecture above, though it will also provide some guidance about alternative ways to value large, spatially differentiated regulations.

To proceed, I make simplifying assumptions with three objectives. First, to abstract from the sort of detail required of a model that could form a basis for empirical work. This is to increase clarity. Second, to consider simple consumers. Third to limit interactions between firms and consumers.

Consumers are simple in four regards. They have simple preferences. They care only about their consumption of a numeraire good and their pollution exposure, and their preferences are quasi-linear. Second, they are homogenous. Third, they choose only their residential locations, not residential and work locations as in, e.g., Kuminoff (2012) or Fujita and Ogawa (1982). Fourth, there are no barriers to mobility so that agents are able to change locations in response to tiny changes in the environment.

These assumptions stack the deck against rejecting my conjecture. We know that it is more difficult to understand the relationship between behavior and aggregate welfare when individuals face complicated choices, when they have complicated preferences, when they have heterogenous tastes or when their are obstacles to mobility. These are known problems and the paper by Kuminoff in this volume addresses many of these issues. In abstracting from these issues, my goal is to focus on the implications of firm mobility for the calculation of welfare.

The interaction between firms and consumers is artificially simple in three regards. First, firms and consumers do not compete for land, contrary to Roback (1982). Second, wages do not vary with the number of firms or with the severity of regulation. Third, product prices do not vary with the locations of consumers. These are purely simplifying assumptions, relaxing them complicates the analysis, but does not qualitatively impact the main conclusion. That is, that the conjecture above is probably false. Considering only the way that consumers value pollution, i.e., benefit-transfer, is unlikely to lead to an understanding of the welfare implications of large, spatially differentiated regulations.

3.1 Firms

The model geography consists of two regions, A and B, indexed by x. The supply schedule for industrial land in region x is

$$R^I(I_x) = r^I + \alpha_x I_x,$$

for $\alpha_x > 0$. That is, I_x units of industrial land are available in region x at rental price $R^I(I_x)$ per unit. R^I represents the sum of land rent paid to absentee landlords and routine transportation costs.[1] Price taking firms make a single unit of output q and occupy a single unit of land. Thus, the number of firms in each region is also I_x and aggregate output is $Q = Q_a + Q_B = I_A + I_B$. Aggregate inverse demand function for firm output is $P(Q) = D_0 - D_1 Q$. Pollution and fixed inputs are also inputs into the production process, and in addition to land rent. Each firm's cost function is $F + \max\{s^* - s, 0\}$. Here, F is a fixed cost, s^* is a parameter, the maximum amount

[1]More detailed micro-foundations consistent with this specification are developed in Desmet and Rossi-Hansberg (2013).

of pollution an unconstrained firm will emit, and s is the firm's choice variable, the amount of pollution the firm actually emits.

The firm's problem is to solve

$$\max_{s} \pi_x = P - R_x^I - [F + \max\{s^* - s, 0\}],$$

for $s^* > 0$. By inspection, the firm will always choose $s = s^*$ unless regulation constrains them to do otherwise, and profits will be given by $\pi_x = P - R_x^I - F$. Firms enter each region until land rents increase to the point that profits are zero.

We will be interested in regulation restricting the ability of firms to pollute. Represent such regulation as a jurisdiction specific cap on a firm's pollution output, $s_x < s^*$. In the presence of such regulation, firm profits become $\pi_x = P - R_x^I - F - (s^* - s_x)$. The aggregate level of pollution in region x, S_x, is the sum of pollution over all firms, so $S_x = I_x s^*$ if region x is unregulated and $S_x = I_x s_x$ when it is regulated.

In equilibrium firms enter each region until profits are zero. When output prices are given by the aggregate inverse demand equation. It follows that the equilibrium distribution of firms must satisfy

$$P(I_A + I_B) = R^I(I_A) + F + (s^* - s_A)$$
$$P(I_A + I_B) = R^I(I_B) + F + (s^* - s_B)$$

To solve for the equilibrium number of firms in each region equate the right hand sides of two expressions above and substitute from the definition of R_x^I to obtain

$$I_A = \frac{\alpha_B}{\alpha_A} I_B + \frac{s_A - s_B}{\alpha_A}.$$

Substituting into the first of the two equilibrium conditions and solving gives the equilibrium populations of firms in region B, I^*B,

$$I_B^* = -\frac{\alpha_A(-D_0 + r^I + F + (s^* - s_B)) + (D_1 + \alpha_A)(s_A - s_B)}{(D_1 + \alpha_A)\alpha_B + D_1 \alpha_A}$$

and a symmetric expression for I_A^*.

Equilibrium changes in the populations of firms as regulation changes in own and other jurisdiction are of particular interest. Using the expression above, we have

$$\frac{\partial I_B^*}{\partial s_A} = \frac{-(D_1 + \alpha_A)}{D_1(\alpha_B + \alpha_A) + \alpha_B \alpha_A} < 0 \quad (1)$$

$$\frac{\partial I_B^*}{\partial s_B} = \frac{(D_1 + 2\alpha_A)}{D_1(\alpha_B + \alpha_A) + \alpha_B \alpha_A} > 0 \quad (2)$$

Equation (1) is unambiguously negative and (2) positive. Recalling that regulation is *less* stringent as s_x increases, we have that the number of firms in jurisdiction B increases as regulation becomes more stringent in A and decreases as it becomes more stringent at home. Thus, equilibrium comparative statics are broadly consistent with observation. The mechanism by which this occurs is intuitive. In equilibrium, firms enter both jurisdictions until their profits are zero. Restricting pollution in one district drives down profits and reduces the number of firms in the regulated jurisdiction, leading to a supply reduction. The supply reduction raises prices and induces firms to enter in the unregulated district.

3.2 *Households*

There are measure N of households. Each household chooses region A or B and then consumes one unit of residential land, provides one unit of labor and experiences the regional pollution level. Region x contains measure N_x of land suitable for residential use and $N_A + N_B \equiv N$. Firms and consumers do not compete in the same land market.

Let w_x, S_x and r_x denote wages, pollution (smoke) and residential land rent in region x. Assume a household's utility in region x is given by $u_x = w_x - r_x - S_x$. Households like income and dislike pollution and land rent. Absentee landlords own all of the residential land in the economy. Their only role is to collect land rent, which then leaves the model.[2]

Equilibrium regions for firms imply equilibrium levels of pollution, $S_x^* = I_x^* s_x$. With these pollution levels determined, we can characterize equilibrium in the housing market. Because the exogenously determined measure of residents and land is exactly equal, equilibrium is particularly simple. It a price such that no resident wants to change their location. That is, the equilibrium prices of land must satisfy,

$$u_A = u_B$$

$$w_A - r_A - S_A^* = w_B - r_B - S_B^*$$

This implies that

$$r_B = r_A + (w_B - w_A) + (S_A^* - S_B^*) \tag{3}$$

[2] This is a common simplifying assumption in spatial models. It allows me to avoid the cumbersome problem of specifying an ownership structure for land and recirculating land rent through the economy.

In words, free mobility requires that rent in jurisdiction B increase relative to rent in jurisdiction A when pollution declines in B or rises in A and when wages decline in A or rise in B. This, too, is broadly consistent with observation. Land prices go down in places where air quality is worse.

3.3 *Discussion*

The model relies on strong simplifying assumptions. Basically, it includes the minimum amount of structure required to allow the model to match the two stylized facts that started this section; firms flee regulation and people like clean air. A number of these simplifying assumptions deserve comment.

First, the model does not include enough structure to identify the absolute level of residential land rent, only the relative level. There are two conventional generalizations that solve this problem. The first involves fixing an outside utility level and permitting agents to migrate in our out of the study are until utility in the study are equals the reference value. The second involves allowing for surplus land which may be rented at a reservation price. This identifies the rent for the least attractive occupied location in the study area. The present simplification contains enough detail to provide a transparent illustration of the way that amenities are capitalized into land prices but avoids some complexity.

Second, land cannot be converted between residential and industrial use. This is purely a simplifying assumption. Relaxing it requires that land rent be equal for residential and industrial use, and that the supply of residential land, therefore, be somewhat elastic. This is, in turn, requires that we adjust the land market equilibrium to allow for an elastic supply of land in both jurisdictions and that we keep track of an extra equilibrium condition: land prices are the same for firms and households.

Third, firms do not use labor, and wages do not depend on firm productivity. These are also straightforward generalizations, and are central to the classic analysis of Roback (1982). If pollution regulation affects labor productivity, this will affect household location choices and land prices in both residential and commercial land markets.

Finally, as noted above, the supply of residential land is fixed. This means that any change in the attractiveness of one location must affect the residential land market in the other. This assumption is convenient for my purpose, but allowing for land supply elasticity as I have done for industrial land is also of interest.

3.4 *Experiment I: Identifying demand parameters*

I would now like to consider the problem of evaluating a particular regulatory restriction. To begin, consider the simpler case where we observe a change in pollution, unrelated to policy.

Specifically, suppose that at an initial time, $t = 0$, jurisdictions A and B are ex ante identical, i.e., wages and pollution equal, and that in a subsequent time, $t = 1$, we decrease pollution in jurisdiction B by an amount Δ. Using superscripts to denote time, we can calculate the cross-jurisdiction land rent gap in each period from equation 3

$$r_B^0 - r_A^0 = (w_B^0 - w_A^0) + (S_A^0 - S_B^0) = 0 \tag{4}$$

$$r_B^1 - r_A^1 = (w_B^0 - w_A^0) + (S_A^0 - (S_B^0 - \Delta)) = \Delta. \tag{5}$$

If we observe this process, we will see that a decrease in pollution of Δ in region B is matched with an increase in unit land rent in region B of the same magnitude. Comparing these, we will correctly infer that the marginal disutility of pollution is exactly 1. We can also calculate the Benthamite welfare value of this change in pollution by summing the change in land rent over all households to get $\Delta \times N_B$.

Thus, in our simple model, the problem of estimating and valuing changes in pollution is straightforward. In particular, if we once know the marginal disutility of pollution, we can apply this estimate to other problems in a straightforward way.

We note that the simple relationship between land rent and preferences for pollution depends on the simple structure of the model we consider. As we consider more realistic environments, particularly those involving heterogeneity in consumers preferences for locations or pollution, knowing changes in land rent is no longer sufficient to identify preferences for pollution. The paper by Kuminoff in this volume address this issue in detail.

3.5 *Experiment II: Identifying the effects of regulation*

Now consider the problem of evaluating a particular regulatory restriction on pollution. To make our results comparable with the simple reduction in pollution considered above, again suppose that the two jurisdictions are identical in period zero, but at time one, in district B we reduce the amount of pollution that firms can emit by $\delta \equiv \Delta / I_B$. Thus, if all I_B firms reduce their pollution by δ, all else equal, we accomplish a pollution reduction of exactly Δ, just as in the previous section.

In fact, the equilibrium response is more complicated. Using equations 2 and 1, decreasing s_B to $s_B - \delta$ decreases the number of firms in jurisdiction B by $\frac{\partial I_B}{\partial s_B}\delta$ and increases the number of firms in jurisdiction A by $\frac{\partial I_A}{\partial s_B}\delta$. Note that, since each firm produces exactly one unit of output, changes in the aggregate stock of firms will imply changes in aggregate firm output and, hence, in the price of this output.

This change in firms means that the change in pollution resulting from the regulation reflects three different effects; the decrease in pollution per firm in jurisdiction B, the decrease in the count of firms in B, and the increase in the number of firms in A. Thus, the change in pollution in jurisdiction B is

$$dS_B = \frac{\partial I_B}{\partial s_B} s_B - I_B \delta < 0$$

and in jurisdiction A

$$dS_A = \frac{\partial I_A}{\partial s_B} s_A > 0$$

On this basis, we can calculate the ex post equilibrium pollution levels in the two districts as $\widehat{S}_A = S_A + dS_A$ and $\widehat{S}_B = S_B + dS_B$.

With ex post pollution levels in hand, we can now characterize equilibrium in the land market before and after the policy intervention. Before the intervention, we have,

$$r_B^0 - r_A^0 = (w_B^0 - w_a^0) + (S_A - S_B) = 0,$$

and afterwards,

$$r_B^1 - r_A^1 = (w_B^0 - w_a^0) + (\widehat{S}_A - \widehat{S}_B) = dS_A - dS_B.$$

Just as in the simpler first experiment, the cross-jurisdiction difference in residential land rent continues to exactly reflect the cross-jurisdiction difference in pollution and leads us to correctly determine that the marginal disutility of a unit of pollution is one.

This conclusion requires two comments. First, in both experiments, the ability of rent differences to measure the value of pollution depends on the fact that wages do not change with pollution or regulation. If, for some reason, wages change in either example, then land rent will confound these wage changes with changes in air quality, the standard intuition from Roback (1982). While this margin of response is not part of the model, it is likely to be relevant in reality. In particular, we should expect wages to fall as firms move from regulated regions. In the example above, this would mean the cross-jurisdiction wage difference moves in the opposite direction of the cross-border pollution difference, leading to an underestimate of the value of pollution. More generally, while land rent changes can capture welfare changes deriving from changes in amenities, in sufficiently complicated environments, e.g. those with preference heterogeneity, it can break down (Kuminoff and Pope (2016), Turner, Haughwout, and Van Der Klaauw (2014)).

Secondly, the migration of firms clearly complicates the welfare evaluation of policies to a great extent. In the case described by equations 4, where we change pollution rather than regulation, we can evaluate welfare by looking at the change in aggregate residential land rent. In the case of changes to regulation, we must consider the implications of changes to residential land rent, changes to industrial land rent and changes in the output good market. This is no longer a simple problem.

4. Two approaches to the evaluation of large policies in the spirit of benefit-transfer

What does all of this tell us about using benefit-transfer methods to evaluate environmental regulations that have pervasive effects on an economy? The simple model developed here shows that evaluating the welfare implications of spatially differentiated regulation is likely to be complex, whether this evaluation relies on benefit-transfer or not.

Models of spatial equilibrium can inform an analyst about the sorts of effects to look for, and the literature provides some evidence about the magnitude of these various effects. Thus, one can imagine evaluating large regulations by enumerating likely effects and using benefit-transfer to estimate their magnitudes. This approach appears to be common.

This method is subject to two criticisms. First, since there is always another hypothetical effect to consider, this method can lead to very long reports. Second, reality is complicated and some important effects of regulation seem obscure enough that it is hard to imagine even a brilliant analyst anticipating them, e.g., the effects on the cement and power industries documented by Ryan (2012) and Gollop and Roberts (1983).

This section suggests two alternative approaches. The first assumes the existence of a literature describing the effects of realized regulations that are similar to the hypothetical regulation, on summary indicators of welfare. The second assumes the existence of a literature, like the one surveyed in section 2, that describes how realized regulations affect two location specific structural parameters, 'productivity' and 'amenities', to evaluate the effects of hypothetical regulations using a model developed in Desmet and Rossi-Hansberg (2013).

4.1 Transferring estimates of the effects of regulation on summary measures of welfare

Rather than attempting to evaluate all of the separate effects of a large regulation, an analyst could instead rely on an examination of the relationship between regulation (or pollution) and some summary measure of welfare. The literature suggests a two ways that this might be done.

First, at an intuitive level, making places that people want to live is better than making places that they don't. Thus, a minimum test for a large regulation might be that more regulated jurisdictions attract people from less regulated jurisdictions. This approach has been used to evaluate infrastructure construction in Duranton and Turner (2012) and Gonzalez Navarro and Turner (2016), who also provide more discursive arguments for its use.

Implementing a benefit-transfer like version of this method requires a literature which describes the effect of related regulations on the distribution of population. Given such a literature, an analyst could assess whether regulations similar to the hypothetical regulation attract or repel people. The past several years has seen the emergence of a literature which evaluates the ability of large transportation infrastructure projects to reorganize population. To my knowledge, no comparable literature exists for environmental regulations, though encouraging such a literature would seem to be a priority.

Second, the classic 'Rosen-Roback' model develops the hedonic estimation technique in the context of a free mobility equilibrium (Roback, 1982). In this model, policy innovations are good if they lead to *decreases* in disposable income in places subject to the policy. The intuition for this seemingly counterintuitive result is straightforward. In a free mobility equilibrium all locations must provide the same level of utility (to identical agents). Given this, if a decrease in pollution makes a location more attractive, then preserving the equal utility condition requires an increase in the rental price of land. This logic defines 'nice places' to be those where people want to live in spite of housing prices that are high relative to wages. This approach to valuing local public goods has been applied to local climate by Albouy, Graf, Wolff, and Kellogg (1982). To my knowledge, it has not been used to evaluate the Clean Air Act, or similar large environmental regulations, although Chay and Greenstone (2005) (for example) look at the impact of the Clean Air Act on housing prices, which is an important part of the Rosen-Roback calculation.

4.2 *Benefit-transfer and structural models of spatial equilibrium*

While the Rosen-Roback model provides a powerful analytical framework in which to consider the welfare implications of location specific policies, it treats only a single location. Thus, it may not be adequate for the analysis of policies that, like the Clean Air Act, induce a shuffling of activities across locations. In particular, a common empirical implementation of the Rosen-Roback model involves estimating the effect on location specific wages or housing prices of a 'treatment', for a set of treated and control locations. Implicit in this design is the assumption that control locations are unaffected by the treatment. For large, spatially differentiated regulations, like the Clean Air Act, this implicit assumption may be violated.

The literature has developed three main alternative approaches to address this class of problems empirically. These approaches are based on three different literatures, trade, I/O and urban. Redding (2016) provides a framework, based on a model of Ricardian trade, in which the general equilibrium problem is explicit. He considers a system of locations in which the mobility of individuals across locations is free, i.e., a free-mobility equilibrium in the sense of Roback (1982), but trade in goods is costly. In this context, he finds that welfare is determined by population levels and by the extent to which a city trades with other cities.[3] To the extent that large regulations seem to relocate production in different ways than they relocate population, the attention to trade permitted by this framework may be informative.

Diamond (2016) develops an empirical implementation of a generalization of the Rosen-Roback model that explicitly allows the migration of people and economic activity. The principal advantage of this framework is that it permits the application of econometric methods from I/O to the problem. This is an important advantage. The other two frameworks rely heavily on calibration, and so should probably be regarded as less accurate. However, Diamond (2016) is about income inequality and sorting, and its methodology has not yet been widely applied to environmental problems. In addition, the econometric sophistication of Diamond (2016) means that applying the method to other problems requires a major effort that is inconsistent with the idea of benefit-transfer.

Desmet and Rossi-Hansberg (2013) develops a tractable model that generalizes much of the intuition in Roback (1982) to a general equilibrium environment. Relative to Redding (2016),

[3]Higher levels of trade, income constant, are good because they suggest more specialization in activities where there is a local comparative advantage.

this model provides a richer description of cities and an more rudimentary description of trade. Relative to Diamond (2016) it is calibrated rather than estimated, provides a more complete description of the economy, e.g., capital and land rent are explicit. Importantly, it is much simpler than either Redding (2016) or Diamond (2016) and so appears to be better suited to benefit-transfer like exercises.

Briefly, Desmet and Rossi-Hansberg (2013) develops a steady state model of an economy consisting of many cities in which labor and capital are freely mobile, and in which each city provides utility to its residents as a function of three fundamental parameters, one describing productivity, one describing amenities, and one describing government productivity.[4] Given this set of three fundamental parameters for each location, the model exactly predicts the observed state of the world and allows the evaluation of counterfactual scenarios under hypothetical values of the these fundamental values. In particular, given hypothetical values of the three sets of fundamental parameters, we can evaluate counterfactual welfare as well as the distributions of population and economic activity across cities.

The possibility of evaluating counterfactual scenarios 'easily', by using the Desmet and Rossi-Hansberg (2013) framework suggests a possibility for extending benefit-transfer methodologies to the evaluation of regulations with pervasive effects. Such an evaluation would proceed in two main steps.

First, the discussion in section 2 revolves around papers that describe the effect of the Clean Air Act on either firm productivity or on the amenities associated with particular places. Thus, on the basis of the existing literature, we can imagine guessing at how the Clean Air Act changed productivity and amenity values in particular places. Given such guesses, we could use the model to evaluate the ways the Clean Air Act changed patterns of location and production.[5] Moreover, since the Clean Air Act has been so extensively studied, we could validate this exercise against what we know about the effects of the Clean Air Act, e.g., Chay and Greenstone (2005), Becker and Henderson (2000), Walker (2013).

Second, with a calibration of the Desmet and Rossi-Hansberg (2013) model in place, and in particular, with a calibration that is reasonably accurate at predicting known effects of the Clean

[4]Each city is, therefore, slightly more complicated than the basic Rosen-Roback city in that it allows for a government sector which provides local public goods.

[5]There is no reason to think that the Clean Air Act affects government productivity, so these parameters all stay unchanged from the Desmet and Rossi-Hansberg (2013) estimates. Indeed, one can imagine a simpler version of their model without a government sector at all.

Air Act, we could then consider the problem of evaluating some new hypothetical regulation, say a change to Clean Air Act. In particular, on the basis of what is known about the Clean Air Act, guess at the effect of the hypothetical regulation on amenities and productivity in each city and then evaluate resulting equilibrium. Thus, we 'transfer' what we know about the implications of the Clean Air Act for productivity and amenities to some other hypothetical regulation by supposing that its effects on productivity is related to those of the Clean Air Act, e.g., proportional. In this context, the problem of benefit-transfer becomes one of assessing these counterfactual amenity and productivity values. Given a guess at these structural values, we can then guess at the full general equilibrium effects of the hypothetical regulation.

4.3 Two further issues

Two important conceptual issues remain. First, in the context of the application of the Desmet and Rossi-Hansberg (2013) framework suggested above, how can we deal with the fact that different regulations may affect the economy through seemingly different mechanisms? For example, the Clean Air Act will primarily affect the productivity of non-attainment regions, but will affect air quality much more broadly, while the clean water act will affect industries that produce water pollution almost everywhere, but affect amenities only for people who live near or rely on the protected waterways. While these effects are clearly quite different from a practical point of view, from the point of view of the modeling exercise described above, they are not. Each can be represented as change in a subset of the location specific productivities and amenities.

Second, when should we worry about regulations being 'big enough' that the attention to general equilibrium effects suggested by this article makes sense? This question does not seem to have a straightforward answer. In particular, the extent to which a regulation has important general regulation effects depends both on the nature of the regulation and on the importance of general equilibrium margins of adjustment. If moving is extremely costly for regulated firms or affected populations, then regulations which have small effects on pollution are unlikely to induce much mobility. Conversely for highly mobile firms and people. Thus, whether a regulation is big enough to justify worrying about general equilibrium effects appears to be an empirical question.[6]

[6]Note that this echoes the problem of determining local labor employment elasticities. The way a region responds to an employment shock appears to depend, for example, on how easy it is for people to commute into this market or how elastic is the housing supply.

5. Conclusion

Benefit-transfer *per se*, is common practice throughout the economics profession. It is the usually the unremarked practice of using estimates of structural parameters from one context to investigate other related problems. Our willingness to rely on such estimates rests on both the credibility of the parameter estimates in question, and on the axiom that similar decision environments elicit similar behavior.

This analysis makes two main points. First, that evaluating large spatially differentiated regulations like the Clean Air Act is a complicated business, and that many of the effects of regulation may revolve around the migration of people and firms towards or away from more regulated areas. This point is fundamentally related to how we approach the problem of evaluating hypothetical regulations. In general, such evaluation should consider the possibility of migration and general equilibrium effects, and hence, should be concerned with the availability estimates of parameters describing these types of responses to regulations, not simply with preference parameters.

Second, the analysis suggests two benefit-transfer 'like' methods for evaluating hypothetical regulations on the basis of pre-existing estimates. The first relies on a literature describing how related regulations affect population and real incomes as a basis for guessing the effects of hypothetical regulation. Such a literature appears to be, itself hypothetical at this time, though a related literature assessing the effects of transportation infrastructure has developed rapidly over the past several years. The second method relies on a particular tractable general equilibrium model that allows the evaluation of the general equilibrium implications of any hypothetical regulation that we can characterize as changes to observed location specific productivity and amenities. The available literature on the Clean Air Act should allow us to estimate how the Clean Air Act changed these parameters, and also to guess at how hypothetical regulations might change these parameters. Together, the model and estimated changes to productivity and amenities allows an evaluation of general equilibrium implications of hypothetical large regulations.

The discussion above is a description of a method, not proof of concept. Thus, it remains to implement the methods described above, and this agenda faces important problems. First, the determination of whether a regulation is large enough to merit this sort of analysis appears to be an empirical question, and one about which we have limited understanding. Second, the 'summary statistic' approach rests on a literature that may not exist. Third, the available estimates of the

Desmet and Rossi-Hansberg (2013) will ultimately go out of date and become obsolete, while improvements to our understanding of general equilibrium structural models and estimates are ongoing. At a minimum, a commitment to the use of the Desmet and Rossi-Hansberg (2013) framework, or a competing model, involves a commitment to keep calibrations of this model up to date. In short, the interest in using benefit transfer to estimate preference parameters in situations similar to known situations precipitated a research effort to develop a 'reference library' of preference estimates. So too, an interest in evaluating hypothetical large regulations requires a reference library describing structural parameters of a carefully chosen general equilibrium model (or family of models).

Finally, I note the relevance of this research to the Clean Water Act. The Clean Water Act appears to have been subject to much less academic scrutiny than has the Clean Air Act. Dornbush and Abel (1973) provides an analysis of the relationship between water quality and residential land prices and finds a strong cross-sectional relationship. More recently, in a definitive working paper, Keiser and Shapiro (2016) document the effects of the Clean Water Act on water quality and housing prices using modern research designs to identify causal effects. They document that the clean water act involves the construction of expensive infrastructure, that compliance may vary with state level policy and that there are modest increases in near water land prices as water quality improves. They do not investigate the extent to which the clean water act induces the movement of people or firms. To my knowledge, we do not yet have an empirical basis for estimating the sizes of such dislocations, though it may be possible to make reasonable guesses on the basis of what is known about the Clean Air Act. Such guesses, together with methods suggested above could provide a basis for thinking about the welfare effects of this act when we allow for spatial equilibrium responses to the regulation.

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