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Adaptation, Internalization and Environmental Damage*

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ABSTRACT

Existing literature ignores adaptation responses to external effects which, in turn, affect the design of appropriate internalization instruments. We use general equilibrium numerical simulation models based on OECD and UK data to analyze the significance of these responses to congestion externalities, and argue that they need to be taken into account in designing internalization instruments. We consider labor-leisure, regional labor mobility and house price responses to congestion externalities. Results show that not taking adaptation responses to environmental damage into account can seriously mislead analyzes of the consequences of internalizing externalities. If adaptation is present, externalities will be partially internalized, the gains from internalization will be smaller, and a simple internalization tax calculated as if adaptation were not present will typically overcorrect for the externality.

KEY WORDS: Adaptation, Externalities, Congestion, Internalization, Migration.

JEL CLASSIFICATION: H2, Q3, R4, R13.

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1 Introduction

The literature on externalities begins with Pigou's (1924) identification of the difference between marginal social and private benefits (or costs) and the need to correct for this with a tax or subsidy. It continues with Coase's (1960) seminal paper which identifies the importance of property rights in designing internalization instruments. This literature argues that the difference between alternative property rights lies mainly in income distribution effects, and that prior bargaining (Coasian deals) between the parties can (wholly or partially) internalize externalities before any other policy instrument is used. Policy instruments designed in ignorance of such bargaining can overcorrect for an externality.

This paper continues this discussion by also arguing that adaptation (or behavioral responses) to the damage associated with externalities, a pervasive phenomenon and one ignored in the literature, can also affect internalization instrument design. Examples of this type of adaptation include individuals spending more time indoors when ultraviolet radiation increases as damage to the ozone layer occurs; relocating upstream when fishing stocks are adversely affected by pollution; moving between locations due to localized emissions; or switching travel times in order to avoid traffic congestion. We argue that these behavioral responses need to be accounted for in any policy intervention designed to internalize externalities. Ignoring them will typically yield outcomes which overcorrect for the externality.

In the case of traffic congestion, the externality widely thought to need correction is that the marginal private and social cost of driving differ, with the latter needing to be taken into account when making transit decisions and motivating transit taxes. With a labor-leisure choice underlying decisions of workers who travel, we argue that the presence of damage (avoided by not working) also creates a wedge between the marginal value product of labor and the marginal value of leisure, as individuals adapt to the damage and modify their labor supply behavior. Internalizing congestion externalities through a tax on transit which reduce the number of travelers increases the wedge between the marginal product of labor and the marginal value of time if there is diminishing marginal productivity of labor in the workplace. In this case, neglecting the adaptation to damage overestimates (potentially sharply, as we show later by numerical simulations) the true welfare gains from internalization.

In the widely used environmental texts, such as Baumol and Oates (1988), Pearce and Turner (1990), and Siebert (1995), we find no discussion of this adaptation issue. Classical papers in transport economics, including Walters (1961), Johnson (1964), and Else (1981), and recent texts such as Button (1993a), Button (1993b) and Verhoef (1996), begin from the proposition that appropriate internalization of congestion externalities involves a transit tax reflecting the difference between marginal private and social cost, and neglects the adaptive behavioral responses we highlight here.[1] The point has wide application and potentially sharply changes the evaluation of appropriate environmental policies.[2]

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[1]Other literature examines the effects of congestion externalities on residential land use, emphasizing the distortion in land markets created by them (e.g. Arnott and MacKinnon, 1978; Henderson, 1975; Solow, 1973). Sullivan (1983a, 1983b), in particular, extends previous land-use models by including a labor demand sector and considering not only residential land but also industrial and transportation land, showing that unpriced congestion externalities distort housing, land and labor markets, which, in turn, generate inefficiencies in commodity markets. None of this literature, however, considers the adaptation effects on instrument design we stress here.

[2]Recent econometric iterature explores unintended consequences of environmental policy, but does not make the link to the design of internalization measures that we make here. Kahn (1998),

In developing our theme, we use a hierarchy of numerical models of instrument design responding to congestion externalities, and appeal to OECD data and estimates from studies in calibrating and parameterizing them. In our first model the structure is kept simple, with one produced good, work-related transit, and damage in the form of congestion (time and traffic-related health effects). In this model we consider labor-leisure responses as the adaptation vehicle, with individuals assumed to avoid damage by not working. We then consider a model with regional labor mobility and region-specific congestion damage, where adaptation occurs in the form of induced migration responses.

We consider various embellishments on this basic regional structure. One includes local housing markets, with regional house prices adjusting to migration induced by localized damage and acting to damp migration. Here, changes in house prices reflect the adaptation response to region-specific damage. Another is fiscal effects, since if revenues from any internalization tax accrue solely to one region, adaptation responses are affected by revenue redistribution across regions. Yet another is region-specific production-related damage in the form of utility loss for residents of the affected region. Here, again, migration is the adaptation response, but two instruments are needed to internalize the externality—a sector-specific production tax and a region-specific labor subsidy.

The issue of how to allow for adaptation responses in instrument design remains the same through all these cases. Internalization instruments designed as though

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for instance, estimates the relationship between environmental quality improvement and household migration in California. Other studies in this vein include Becker and Henderson (1997), Berman and Bui (1998), Kahn (1997), and Levinson (1996).

adaptation is not present differ significantly from those which take adaptation responses to damage into account. Typically, gains from internalization are substantially smaller than those in comparable models which ignore adaptation responses, as are externality correcting taxes or subsidies. In the language of the literature on the Coase theorem, the issue is not only whether partial internalization of externalities has occurred through Coasian deals, and so a simple Pigouvian tax overcorrects for them; it is also whether any adaptive response to the externalities has also taken place.

2 Internalizing Congestion Externalities in the Presence of Labor Market Adaptation Responses

We first consider a simple model of congestion externalities in which labor supply decisions adapt to the time loss in traffic in various ways. One is by modifying the amount of labor supplied to the market; another is by relocating from cities to rural areas. We build on literature which estimates the social costs of traffic-related external effects in cities. These include excess time use in traffic, noise, elevated accident rates, and the impact of sulphides, nitric oxides, and particulate matter on human health, material damage and plant life. Khisty and Kaftanski (1986) some years ago produced an estimate that the added social costs in the US were in the order of 38 cents (at 1982 prices) per extra vehicle mile; perhaps 20 times the then price of gasoline.[3] A more recent OECD (1994) report puts congestion-related additional

[3]Khisty and Kaftanski (1986) also produced component estimates for extra travel time as (in cents): air pollution (2), noise pollution (4), excess fuel consumption (11), additional accidents (13), and others effects (11).

time use (relative to free flowing traffic) at 2-3% of GDP for OECD economies, noise costs at 0.3%, accident costs at 1.5-2%, and local pollution at 0.4%; in total 4-6% of GDP. For the UK, Newbery (1995) reports an estimate (for 1993) of congestion costs from additional time use as equivalent to 3% of GDP.[4]

These are large orders of magnitude, with seemingly significant gains achievable from internalization. Our point of departure is that with localized external effects individuals can adapt to the damage they suffer if they travel to work. One simple way is to reduce time supplied to the market, but other more subtle responses occur, such as changing the time at which transit occurs. Because these effects are present in the pre intervention equilibrium, they affect the perceived welfare gain from internalizing the externality. A Pigouvian tax or subsidy seeking to correct for the difference between average and marginal damage (marginal private and social costs) as a way of generating the social gain from internalization which misses the changes in these adaptation responses as internalization occurs typically overestimates the gain.

Labor-Leisure Response

We make our argument by first examining a simple case of congestion externalities in the presence of labor-leisure choice. We consider a short run, in which additions to road capacity to deal with congestion are taken as infeasible.[5] The damage function

[4]Small (1992) and Miller (1989) find cost of travel time figures for the US of 50% and 60% of the hourly wage, respectively. More recently, Calfee and Winston (1998) have estimated the value of transit time for the US based on a willingness to pay (WTP) survey, and find an average WTP per hour of 19% of the gross hourly wage, considerably smaller than other studies, though—unlike OECD (1994)—it reflects time loss only.

[5]Significant increases in capacity or infrastructure within (as against between) urban areas are

from congestion we consider is, for now, defined over the number of workers in transit in urban areas, ruling out more sophisticated mechanisms through which existing urban residents can jointly reduce damage by, say, staggering transit times to work.[6]

We consider the starting point for gains occurring from internalization to be one where Coasian (Coase, 1960) bargaining has not already occurred. Motorists are thus not jointly bargaining to mitigate congestion damage. We regard this as a reasonable assumption given the large transaction costs involved in this case.

Given these assumptions, we consider a fixed number of workers, $\bar{L}$, each of whom has identical homothetic preferences. Each worker has a fixed endowment of time, which we take to be unity. Workers decide on how much of their time to devote to market activity (which requires transit, and hence congestion), and how much to devote to leisure, which, for simplicity, we assume to be free of congestion. We denote aggregate time devoted to production by all workers as L, L being measured net of transit time. Market production is given by a decreasing returns to scale production function:

$$Y = L^{\alpha}; \quad \alpha < 1 \tag{1}$$

where Y denotes output. The parameter α is strictly less than one, and defines the elasticity of output with respect to the labor input. The average product of labor (Y/L) exceeds the marginal product $(\alpha Y/L)$.[7] With the formulation used here rents

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thus assumed away. This can be due to political opposition to new roads by existing residents, unwieldy legal process for compensation, or other considerations.

[6]In reality, such mechanisms are clearly important, but we ignore them for now both to simplify the analysis and to keep the focus on our main point.

[7]Equation (1) can be reformulated as constant returns to scale by adding a fixed factor with a

also accrue to an unspecified non-labor, fixed factor. We assume that these rents accrue to households (implicitly through ownership of the fixed factor) in lump-sum form.

We assume a damage function from congestion which is increasing in the market-supplied labor input, L

$$D = \lambda L^{\gamma}; \quad \gamma > 1 \tag{2}$$

where D represents total damage (here denominated in units of labor), $D/\bar{L}$ is the damage per market participant, λ and γ are parameters of the damage function. $\gamma > 1$ implies that marginal exceeds average damage.

We assume households have a utility function defined over goods (Y) and leisure (E) consumed:

$$U = U(Y, E) \tag{3}$$

where

$$E = 1 - L/\bar{L} - D/\bar{L} \tag{4}$$

The equation for E reflects an endowment of time per household of unity, market labor supply per household of $L/\bar{L}$, and damage per worker (in time units) of $D/\bar{L}$.

Households maximize utility subject to a cash budget constraint

$$P_Y Y = W\frac{L}{\bar{L}} \tag{5}$$

where P_Y is the price of the good, Y, and W is the market wage.

Cobb-Douglas share (1-α).

The externality that congestion creates in this case is that individual workers respond to the average (or private) cost each of them faces in transit, not to the marginal (or social) cost. From (2), marginal damage exceeds average damage, and there are gains to be had from internalization. However, because of adaptation responses to damage, a wedge also exists in the with-damage equilibrium between the marginal value product of labor in goods production—which equals the wage rate—and the marginal value of time in leisure consumption (marginal utility of leisure). Through adaptation individuals can mitigate damage by not working, and hence equate the market wage net of damage per unit of labor supplied to the marginal utility of leisure:

$$W\left(1-\frac{D}{L}\right)=U_E \tag{6}$$

where U_E is the marginal utility of leisure.

In this case, internalization instruments can reduce damage, but they also alter the adaptation to the damage. A transit tax reduces output, and hence damage, but in doing so it also further increases the marginal product of labor in goods production. The distortion between the marginal product of labor in goods production and the marginal value of time in leisure consumption is intensified by internalization, and the gain from internalization is reduced. The appropriate internalization tax rate calculated in models with adaptation will differ from those where adaptation is absent.

In contrast, if adaptation responses are not present, individuals equate the market wage to the marginal utility of leisure:

$$W=U_E \tag{7}$$

Damage still occurs, and affects market output through (2) and (4), but no internalizing adaptation occurs. An optimal internalizing transit tax based on (7) would typically be larger than one based on (6), and so would be the perceived welfare gains from internalization. These effects occur simply because adaptation responses to damage have already partially internalize the externality.

We illustrate these impacts of adaptation by calibrating the simple model set out above to a 1995 UK data set on production, consumption, and congestion-related damage and performing general equilibrium numerical simulations. We compute optimal internalization tax rates, and the gains from instituting them, both in the presence and the absence of adaptation responses. The calibration is based on UK GDP in 1995 in the region of 700 billion pounds (1 trillion US dollars). Assuming a work force of 25 million, this gives an annual income per member of the work force of around 40,000 US dollars. We use the labor share in the value of market production implied by 1995 UK national account data (0.68), and take the leisure share in expanded income (market income + leisure) to be 3/7.

For calibration on the environmental side, the OECD (1994) report we refer to earlier cites two different estimates of economy-wide congestion-related costs; one based on total time lost, equivalent to 8.5% of GDP, and the other 2-3% of GDP based on time lost compared with free-flowing traffic. Combining the first estimate with accident costs (1.5-2% of GDP), noise costs (0.3% of GDP) and local pollution costs (0.9% of GDP) yields a total congestion-related damage figure of 11-12% of GDP. Based on this figure, and trying to capture total rather than only congestion-related damage, we take total base-case damage for the UK as being 10% of GDP.

Using these data we are able to calibrate share parameters for goods and leisure consumption for Cobb-Douglas preferences. Assuming a damage function elasticity, γ (which we set equal to 1.5), we can then determine the other parameter, λ, of the damage function. Part A of Table 1 summarizes both the data used in and the parameters generated by these procedures.

Table 1: Model Experiments Internalizing Congestion Damage with and without Labor-Leisure Adaptation Responses

A. Specification of Base Case	
UK GDP (billion pounds)	700
Congestion-related damage (billion pounds)	70
Labor share in market production	0.68
Leisure share in expanded income (market income + leisure)	3/7
Share of goods in preferences (β_G)	0.56
Damage function elasticity (γ)	1.5
B. Internalization Impacts with Adaptation Responses (%)	
Optimal tax rate on market labor supply	7.2
Internalization gain (EV as % of GDP)	0.08
Change in labor supplied to the market	-3.3
C. Internalization Impacts with No Adaptation Responses (%)	
Optimal tax rate on market labor supply	21.0
Internalization gain (EV as % of GDP)	0.71
Change in labor supplied to the market	- 9.5

Our simulation results (both in the presence and absence of adaptation responses) are reported in Table 1. With adaptation responses, we show a transit tax of 7.2% as being needed to achieve full internalization, and an associated welfare gain of 0.08% of GDP. This is an extremely small number compared to the damage in the base case, but in the absence of adaptation responses it increases sharply. Gains from internalization calculated as though there were no adaptation response are nearly nine times larger, at 0.71% of GDP, and the optimal internalization tax rate is 21%.

Market labor supply responses differ by a factor of nearly three across those cases. Including or excluding adaptation responses to damage makes a large difference to the design of appropriate instruments to internalize externalities.

Table 2: Sensitivity of Internalization Impacts in Table 1
to Key Model Parameters

	γ=1.1	γ=2.0	β_G=0.8
A. With Adaptation Responses(%)			
Optimal tax rate on market labor supply	1.5	14.0	7.3
Internalization gain (EV as % of GDP)	0.003	0.29	0.004
Change in labor supplied to the market	-0.72	-5.7	-1.6
B. With No Adaptation Responses(%)			
Optimal tax rate on market labor supply	16.0	26.1	21.5
Internalization gain (EV as % of GDP)	0.42	1.1	0.36
Change in labor supplied to the market	-7.6	-11.3	-5.0

Sensitivity analyzes on the results from Table 1 using variations on key model parameters are reported in Table 2, again for cases with and without adaptation responses. These results suggest that the large differences between cases with and without adaptation responses prevail. Increasing the elasticity of the damage function (γ) increases the gains from internalization since both average and marginal damage increase. Variations occur in impact also under changed preference parameters, but the theme of the importance of adaptation assumptions still prevails. *Interregional*

Labor Locational Response

A further way in which adaptation responses to congestion damage can occur is where damage is localized and locational choice is present. To show how this further element of adaptation response can affect instrument design, we build on the literature on interregional labor mobility associated with Flatters, Henderson and Mieszkowski (1974), Boadway and Flatters (1982), and Myers (1990), among others, and add region-specific environmental considerations to the model above. Flatters, Henderson and Mieszkowski show how local public goods financed by taxes on residents can generate inefficient migration, since wage rates differences across regions can be supported by differences in individual benefits less taxes. In our structure, we assume damage is region-specific, and that migrants respond by comparing the wage premium they can receive if they remain in the affected region to the cost to them of the damage they incur. Adaptation to region-specific damage in this case generates migration.

We consider an economy with two regions, labeled as U (for urban) and R (for rural). Environmental effects occur in only one of the two regions, and affect interregional labor migration. For now, we assume there is congestion-related damage within the U region, affecting only the region's residents.[8] We also assume that labor is interregionally mobile.

We assume again that the economy has a fixed endowment of labor, $\bar{L}$, which can move costlessly between the two regions, and that each region has a decreasing returns to scale production function

$$Y^j = (L^j)^{\alpha^j}, \quad j = U, R \tag{8}$$

[8] Thus, by working in the rural region workers avoid the commuting congestion of working in cities; or, alternatively, all residents of urban areas bear congestion costs by living there even if they work somewhere else.

where Y^j denote output, and L^j market supplied labor in region j. The terms α^j are, as above, strictly less than one, and define the elasticity of output with respect to the labor input in region j, with the average product of labor exceeding its marginal product. Rents again accrue to households (implicitly through ownership of fixed factors) from unspecified non-labor, region-specific fixed factors, and in ways that do not influence locational choice.

In this case, we assume damage function which is increasing in the number of residents in cities (L^U):

$$D^U = \lambda(L^U)^\gamma, \quad \gamma > 1 \tag{9}$$

where D^U represents total damage in cities (here again denominated in units of labor). D^U/L^U is the damage per urban resident, and λ and γ are parameters of the damage function. D^R equals zero.

As the single good is homogeneous across regions, it has the same price in both regions, and in equilibrium there is market clearing in both the good and in the labor markets. Consumers in each region maximize utility subject to their budget constraint and producers maximize profits. Because of interregional labor mobility, equilibrium involves an equal-utility condition across regions. With identical preferences for all consumers, interregional differences in wage rates are offset by the value of damage for those locating in region U.

If adaptation behavioral responses are explicitly recognized, this yields the equilibrium condition:

$$W^U\left(1 - \frac{D^U}{L^U}\right) = W^R \tag{10}$$

If no adaptation responses enter, the equilibrium condition is

$$W^U = W^R \tag{11}$$

We consider the internalization instrument in this case to be a tax on inward migration into the congested region (with the revenues distributed equally to residents of all regions). In this case, a trade imbalance for regions is financed by tax revenues received by the other region, and in such cases consumption in region j, C^j , will not necessarily equal regional output, Y^j .

Efficiency conditions in the labor market in this case require that the marginal damage inflicted on by a migrant, rather than the average damage per resident, should affect migration decisions. Thus, in this model, we have different equilibrium and efficiency conditions for the labor market. Where adaptation responses are present, the labor market equilibrium condition implies that

$$W^U(1 - \lambda(L^U)^{\gamma-1}) = W^R, \tag{12}$$

while efficiency requires that

$$W^U(1 - \lambda\gamma(L^U)^{\gamma-1}) = W^R. \tag{13}$$

These conditions imply that the marginal product of labor between the two regions diverges. Any move towards internalization through a tax on migrating labor will once again affect adaptation responses to damage.

In Table 3 we provide a parameterization for this model, again generated through calibration. We also take the UK case, and use it as an example of an OECD country with region-specific congestion. We first calibrate the model to a base case, and then compute a counterfactual in which tax policies are used to internalize the congestion externality, examining cases with and without adaptation responses. We use the same production, labor force and congestion-related cost data as in the previous section, but assume in addition that labor residing in congested regions reflects employment

Table 3: Model Experiments on Internalization of Congestion Externalities with Interregional Labor Mobility

A. Base Case Calibration	
UK GDP (billion pounds)	700
Share of labor in cities	0.6
Region-specific congestion-related damage in the base case (billion pounds)	70
Share of labor in national income	0.68
Damage function elasticity	1.5
B. Internalization Recognizing Adaptation (%)	
Optimal Tax Rate on Urban Labor	3.7
Gain from Internalization (EV as % of GDP)	0.03
Change in Urban Labor	-3.4
C. Internalization with No Adaptation (%)	
Optimal Tax Rate on Urban Labor	30.7
Gain from Internalization (EV as % of GDP)	2.2
Change in Urban Labor	-30.3

in manufacturing (approximately 16% of total employment in 1995), plus one half of employment in services. In combination, this is approximately 60% of the work force. We again use a labor share in total value of production of 0.68, set γ equal to 1.5, and calibrate the values of α^j and λ.

Results in part B of Table 3 show even larger discrepancies in the welfare gains from internalization in the presence and absence of adaptation responses. Gains from internalization if adaptation responses are recognized are only 0.03% of GDP, but 2.2% of GDP if their presence is ignored. Optimal tax rates with adaptation are

3.7%, but 30.7% in their absence, and the changes in labor migration across regions differ by a factor of almost 10. Incorporating adaptation responses makes an even larger impact than in our first model, both in terms of the setting of tax rates and in the perceived welfare gains.

Table 4 presents sensitivity analysis results on the elasticity of the damage function (γ) as well as on the assumed size of damage in the base case. Results again show that welfare gains from internalization are sensitive to model parameter values used, and particularly to the elasticity parameter used in the damage function; but that the sharp differences across cases with and without adaptation responses persist. These sensitivity analyzes also show that the internalization tax rate and welfare gains are inversely related to the size of damage to which the model is calibrated.[9]

3 House Prices and Migration

We next consider an extension to the regional migration model presented above, in which region-specific house prices now enter the picture.[10] This extension yields results in which adaptation effects now occur through housing markets. In this model there are fixed endowments of houses in each of the regions; migration into one region out of the other drives up house prices in the receiving region and drives prices down

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[9]The reason for this is that the internalization tax rises the divergence between urban and rural value marginal product of labor, offseting the reduction in damage and interregional wage rate wedge induced by the tax.

[10]Indeed, in some literature it is common to use indirect measures of location-specific damage as the change in land (or house) prices. See, for instance, some of the studies in Barde and Pearce (1991) and Navrud (1992).

Table 4: Sensitivity Analyses for Internalization Experiments with Congestion Externalities and Interregional Labor Mobility

A. Alternative Parameter Configurations for Sensitivity Cases

	α^U	γ	Value of Damage (% of GDP)	Share of labor in cities
Case 1	0.68	1.3	10	0.6
Case 2	0.68	2.0	10	0.6
Case 3	0.68	3.0	10	0.6
Case 4	0.68	1.5	15	0.6
Case 5	0.68	1.5	5	0.6

B. Internalization Impacts with Adaptation (%)

	Welfare Gain*	Optimal Tax on L^U	Change in L^U
Case 1	0.0001	0.22	-0.22
Case 2	0.25	12.1	-9.1
Case 3	0.92	24.6	-14.6
Case 4	0.0007	0.7	-0.5
Case 5	0.041	3.6	-4.8

C. Internalization Impacts without Adaptation(%)

	Welfare Gain*	Optimal Tax on L^U	Change in L^U
Case 1	1.8	28.8	-28.9
Case 2	3.0	33.4	-31.6
Case 3	4.3	34.4	-31.9
Case 4	4.2	43.1	-38.9
Case 5	0.67	16.6	-18.3

* Hicksian EV as a % of GDP.

in the labor donating region. The effects of region-specific externalities on labor flows are therefore damped by adaptive house price effects, since these affect the migration decision via changes in relative real wage rates across regions. In these cases, potentially large redistribution under internalization can also occur in favor of those owning homes in the non-congested region prior to any intervention to achieve internalization.

More formally, we assume that in each region there is a pre-existing stock of houses, $\bar{H}^U$, $\bar{H}^R$. Houses are infinitely divisible—a larger proportion of the population in a region implies that each individual (or household) lives in a smaller house. Houses across regions are perfect substitutes in preferences, even though the separate fixed housing stocks imply different prices of houses in each region in the presence of region-specific external effects.

Household preferences are written as

$$U = U(C^j, H^j); \quad j = U, R \tag{14}$$

where C^j is the per person consumption of goods in region j, and H^j is the per person consumption of housing in region j. We again use Cobb-Douglas functional forms for (14) in which β_G and β_H denote share parameters on goods and housing.

Given the common goods price, P_C, and the two region specific house prices, P_{H^U} and P_{H^R}, we can construct region specific true cost of living indices from (14) using the expenditure functions

$$\pi^j = g^j(P_C, P_{H^j}); \quad j = U, R \tag{15}$$

These price indices appear in the migration condition (10) and (11) in the presence and absence of adaptation responses in the form

$$\frac{W^U}{\pi^U}\left(1 - \frac{D^U}{L^U}\right) = \frac{W^R}{\pi^R} \tag{16}$$

and

$$\frac{W^U}{\pi^U} = \frac{W^R}{\pi^R} \tag{17}$$

and house prices influence migration decisions through the π^j variables in both the with and without adaptation response cases.

Equilibrium prices for the good, rural and urban housing (in terms of the numeraire, labor) are given by $P^*_{H^j}$, P_C, such that

$$\begin{aligned} H^j &= \bar{H}^j \\ \sum_j C^j &= \sum_j Y^j \\ \bar{L} &= \sum_j L^j + D^U, \end{aligned} \tag{18}$$

We again parameterize this model specification (with housing) using the UK as an economy that is representative of an OECD economy. In our base case, by choice of units the price of housing is unity in both urban and rural areas. We assume (through the choice of $\bar{H}^U$ and $\bar{H}^R$) that 50% of housing (by value) is in urban areas in the base case, and we specify a housing share in preferences of 0.20. We later carry out sensitivity analyzes on these parameter values.

Tables 5 and 6 report model results on the impact of internalization taxes in the presence of house price changes, with and without adaptation responses. Table 7 compares them with the corresponding no house price cases. Results in Table 5 once again show that incorporating adaptation responses sharply reduces optimal tax rates. The presence of adaptive house price responses also substantially reduces the welfare gains from internalization and migration out of the urban areas. This is the result of house prices falling in the cities and rising in rural areas as transit time is taxed and people move out of the cities. This movement in house prices causes

Table 5: Model Experiments on Internalizing Congestion Externalities with Regional House Price Effects

A. Specification of base case	
UK GDP (billion pounds)	700
Share of labor in cities	0.6
Congestion Related Damage (billion pounds)	70
Share of Labor in national income	0.68
Share of national housing value terms in urban area	0.50
Share of housing in preferences	0.20
B. Internalization with Adaptation Responses (%)	
Optimal Tax Rate on Urban Labor	2.7
Gains from Internalization*	0.01
Change in Labor in Cities	-1.3
C. Internalization without Adaptation Responses (%)	
Optimal Tax Rate on Urban Labor	25.5
Gain from Internalization*	1.0
Change in Labor in Cities	-14.1

* Hicksian EV as a % of GDP.

Table 6: Sensitivity Analyses of the Model with Regional House Price Effects

A. Alternative Parameter Configurations

	α^U	γ	β_G	Value of Damage (% of GDP)	Share of labor in cities
Case 1	0.68	2.0	0.8	10	0.6
Case 2	0.68	1.5	0.7	10	0.6

B. Internalization Impacts with Adaptation (%)

	Welfare Gain*	Change in P_H^U	Change in P_H^R
Case 1	0.10	-5.4	10.1
Case 2	0.007	-1.3	2.4

C. Internalization Impacts without Adaptation (%)

	Welfare Gain*	Change in P_H^U	Change in P_H^R
Case 1	1.5	-20.8	37.5
Case 2	0.73	-13.9	24.0

* Hicksian gains as a % of GDP.

Table 7: Comparing Results of Internalization with and without House Price Effects in Cases where Adaptation Responses Are Present

(%)

	Model Variant	Welfare Gain*	Tax on L^U (%)	Change in L^U (%)
Central case	NHPE	0.03	3.7	-3.4
Central case	HPE	0.01	2.7	-1.3
$\gamma = 2$	NHPE	0.25	12.1	-9.1
$\gamma = 2$	HPE	0.10	8.7	-3.7
Damage Value (% GDP) = 15	NHPE	0.0007	0.7	-0.5
Damage Value (% GDP) = 15	HPE	0.0003	0.4	-0.2

HPE : House-price effect

NHPE : No house-price effect

* EV as % of GDP

migration towards the countryside to be smaller as internalization occurs. House price effects also induce a distributional impact against those residing in the cities before internalization.

Sensitivity analyzes (Table 6) show that the large differences in cases with and without adaptive responses prevail across various model parameterizations Increasing the damage function elasticity magnifies these results, while reducing the labor output elasticity in the urban area yields changes in the opposite direction. As in the model with no house prices, increasing the size of the damage in the base case reduces the gain from internalization. Results in Table 7 examine various cases where adaptation responses are present and shows larger welfare gains from internalization compared to no-house-price models, since less adaptation to damage occurs in the base case.

4 Other Influences on Migration

Besides labor supply, locational choice, and house prices, several other adaptation responses to environmental damage occur. In this final section to the paper, we consider two more.

The first is adaptation to region-specific production-related damage, rather than congestion-based damage. In this case, two goods (a clean and a dirty good) enter the analysis, with damage reflecting the production of the dirty good in cities. Adaptation-based migration now results from utility-based damage, rather than a time loss. Importantly in these cases, two interventions (a production and a labor market tax or subsidy) are needed to restore efficiency; a simple Pigouvian production tax will not suffice to fully internalize the externality.

The second case is where fiscal externalities arise if the revenues raised by any internalization tax are returned solely to the affected region, rather than to all residents nationally. Adaptation responses to this region-specific revenue distributional scheme can also affect the choice of internalization instrument, although they are missing in a zero-tax, uninternalized base case.

We again consider an economy with two regions—which, as before, we label urban (U) and rural (R)—and a fixed endowment of labor, $\bar{L}$. Labor can again costlessly move between regions. We consider two goods, clean (C) and dirty (D), each of which can be produced in each region with a decreasing returns to scale technology

$$Y_i^j = (L_i^j)^{\alpha_i^j}; \quad \alpha_i^j < 1; \quad j = U, R; \quad i = C, D \tag{19}$$

where Y_i^j denote outputs and L_i^j denote labor inputs. The α_i^j terms are again strictly less than one, and are equal to the elasticity of output with respect to labor inputs for each good in each region. The average product of labor again exceeds the marginal product of labor in all industries. Goods are mobile and homogeneous across regions, and have the same price (P_i) in both regions.

We consider a case where damage is caused by the production of the dirty good in the urban region, and only impacts residents of cities. We assume that damage takes the form of emissions which lower environmental quality in U. We assume also a fixed coefficient damage function:

$$D^U = \theta Y_D^U \tag{20}$$

where D^U defines the damage in the cities (in units of reduced environmental quality), θ is the damage per unit of production of the dirty good, and Y_D^U is the production of the dirty good in the cities. D^R equals zero.

Environmental quality in each region, Q^j, is given by

$$Q^j = \bar{Q} - D^j; \quad j = U, R \tag{21}$$

where $\bar{Q}$ is environmental quality before damage occurs.

We assume identical preferences for all consumers, with preferences defined over consumption of goods, and environmental quality in each region. Thus,

$$U = U(C_i^j, Q^j); \quad i = C, D; \quad j = R, U \tag{22}$$

Households maximize utility subject to their budget constraint

$$\sum_i P_i C_i^j + \mu^j Q^j = I^j \tag{23}$$

where μ^j represents the shadow price (or marginal valuation) of environmental quality, and I^j is expanded income. Trade between regions can again be generated by internalization policy interventions, such as a Pigouvian production tax on the dirty industry in the cities. Hence C_i^j will not necessarily equal Y_i^j.

In equilibrium, consumers in each region maximize utility subject to their budget constraint, but because of interregional labor mobility, equilibrium now involves an equal-utility condition across regions as well as market clearing in goods and labor. Thus with identical goods prices and preferences across regions, differences in wage rates are offset by the value of production-related damage for those residing in region U.

In the special case where we write (22) in separable form as the utility function per urban resident, i.e.

$$U = U(C_i^j) + V(D^j) \tag{24}$$

we assume that the same damage $V(D^j)$ accrues to all residents of cities. Migration equilibrium in the presence of adaptation responses requires

$$W^U - \frac{V(D^j)}{MUI} = W^R \tag{25}$$

where W^U and W^R are urban and rural wage rates, and MUI is the marginal utility of income.

In the presence of uninternalized damage, (25) will not satisfy the conditions required for Pareto optimality. For efficiency, the wage rate differential (the difference in the value marginal product of labor across regions) should equal the damage in the region caused by the re-location of one extra migrant. Since the marginal product of labor in each region is falling, and as damage is a fixed coefficient multiple of output, marginal damage will be below average damage[11]; and a migration equilibrium will result in too many people remaining in rural areas, i.e. too few people will reside in cities.

An implication of this structure is that, in this case, a physical externality creates a second external effect as migrants respond to average, not marginal damage. As a result, to achieve internalization more than one instrument is needed (i.e. more than a Pigouvian, or production, tax on dirty output in U). An additional instrument, a region-specific labor subsidy or an interregional transfer, is needed.

Previous models can also be modified for externalities of the form that occurs where revenues raised by a region-specific production tax accrue to residents of one region only. If this occurs, fiscally-induced migration, as in Boadway and Flatters (1982) will occur,[12] and these will tend to compound or offset the migration induced

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[11]Average damage is given by equation (20), while marginal damage is

$$\frac{\partial D^U}{\partial L^U} = \alpha_D^U \theta \frac{Y_D^U}{L_D^U}$$

This expression is clearly smaller than (20).

[12]There is an extensive literature on migration and fiscal externalities. Besides Boadway and Flat-

by local externalities. In this case, the wage-arbitrage condition in the presence of adaptation responses given by (25) becomes

$$W^U - \frac{V(D^j)}{MUI} + \tau^U = W^R \tag{26}$$

where τ^U denotes tax revenue per worker in region U ($\tau^R = 0$).

We have used structures incorporating these two sets of additional features to once again analyze the impacts of internalization in the presence and absence of adaptation responses. In numerical implementation we employ UK production and labor force data as in the model from the last section, but we now disaggregate this by industry (clean and dirty). We take the dirty industry to consist of manufacturing and transport activities, which jointly account for approximately 25% of UK GDP. We assume that production of dirty goods (and services) takes place in urban areas only, and that approximately two thirds of clean output is generated in the cities. A substitution elasticity in preferences of 1.5 is used for goods consumption in each region, and goods share parameters are determined through calibration.

We take the value of local environmental damage to be 1% of GDP—roughly consistent with estimates from OECD (1994).[13] Given this estimate, and assuming Cobb-Douglas preferences for goods and environmental quality, and an elasticity of marginal valuation of environmental quality with respect to damage of 0.5 (the value

ters (1982), other papers where this issue is addressed include Buchanan and Goetz (1972), Flatters, Henderson and Mieszkowski (1974), Stiglitz (1977), Hercowitz and Pines (1991) and Burbidge and Myers (1994).

[13]This estimate corresponds to the sum of the costs of noise and local pollution (in terms of health, and material and vegetation damage) for the UK in OECD, 1994.

Table 8: Internalization Effects
in a Production-Based Damage Model

A. Specification of Base Case

UK GDP (billion pounds)	700
Share of labor in cities	0.6
Share of labor in national income	0.68
Labor Output elasticity	
Urban	0.68
Rural	0.68
Preferences elasticity	1.5
CES shares	
Clean.Rural	0.5
Clean.Urban	0.5
Share of goods in preferences	
Rural	0.93
Urban	0.97
Damage (billion pounds)	7.0

B. Impacts of Internalization Taxes (%)

	With Adaptation	Without Adaptation
Welfare gain* from instituting both an optimal production tax and a labor subsidy in cities	0.019	0.022
Welfare gain* from instituting only optimal production tax	0.007	0.021
Optimal production tax rate on Y_D^U when no labor subsidy is used	2.1	3.6
Optimal production tax when subsidy to L_i^U is used	4.25	4.18
Optimal subsidy rate on L_i^U	2.4	0.65

* Hicksian EV as a % of GDP.

used in Perroni and Wigle, 1994), we can simultaneously calibrate the model to an initial endowment of environmental quality ($\bar{Q}$) and a share parameter on environmental quality in preferences. In the process, we choose units such that the marginal valuation of environmental quality is unity in both regions.

Table 8 (Part A) presents and summarizes the parameters and data we use in a production-based damage model. The results show smaller differences between the adaptation and no-adaptation response cases. Note that a the use of only a tax on dirty output yields only part of the gains achievable through internalization. To achieve full gains, a subsidy on urban labor must be employed (Table 8, Part B). As indicated earlier, this is because workers make decisions on migration on the basis of average rather than marginal (smaller) damage, which causes too many people to leave the cities if only a production tax is used.[14] We note that the use of a subsidy induces an increase in the production tax as well. This is because the subsidy, in making urban labor cheaper, causes dirty industry output to increase and further deteriorates environmental quality; the tax increase corrects for this effect.

Results in Table 9 suggest that in the presence of a fiscal externality in the form of (net) tax revenues accruing to urban residents, adaptation has little additional effect on the welfare gain from internalization under different revenue treatments, whereas tax revenue treatment does have an effect without adaptation responses. This because adaptation captures prior migration responses to revenue effects and little extra is gained when they are not recognized. In contrast, in their absence,

[14]When only a production tax is used, the number of residents in the urban area falls by 1.3%; whereas when a subsidy is also introduced, the number of city residents rises by 0.9% (compared to the non-intervention scenario).

Table 9: Tax Revenue Effects and Internalization

(%)

	Welfare Gain (% of GDP)	Optimal Tax on D Prod.	Optimal Subsidy on L_i^U
A. With Adaptation Responses			
Tax revenues accrue to dirty region only	0.0188	4.3	2.2
Tax revenues accrue nationally per capita	0.0189	4.2	2.4
B. Without Adaptation Responses			
Tax revenues accrue to dirty region only	0.0124	3.60	-12.4
Tax revenues accrue nationally per capita	0.0210	3.62	0.0

the migration externality remains uninternalized. Note also that in the absence of adaptation responses, labor in cities must be taxed if revenues accrue to the urban region only. The reason for this is that this revenue distribution scheme will attract too many people into urban areas. If revenue is distributed nationally on a per capita basis, there is no need for a tax or subsidy in the no adaptation case, and full internalization can be achieved by the sole use of a tax on dirty output. In this case, we are effectively back to the traditional Pigouvian world.

5 Conclusion

This paper discusses adaptive effects (or behavioral) responses to the damage associated with externalities, and argues that they are ignored in the literature but can significantly affect the design of policies aiming to correct environmental damage through internalization. These effects occur where households or firms directly modify their behavior in response to environmental damage. Examples include modifying labor supply due to time lost in traffic, moving between locations due to localized emissions, working indoors because of ultraviolet radiation from damage to the ozone layer. We mainly focus on adaptation to congestion-based damage in cities (time loss, noise, accidents, health effects) to illustrate our argument.

We use models calibrated to UK data and results of OECD studies on the cost of damage, as well as to data on the division of the labor force between cities and urban areas. We develop a hierarchy of ever more complex models in which house price effects (which dampen mobility), production externality effects, and region-specific tax revenue effects are taken into consideration and generate various adaptation responses. In all cases, adaptation responses to damage occur and affect pre-internalization equilibrium outcomes and partially internalize the costs of damage. Gains from internalizing externalities so as to correct induced misallocations of resources are considerably smaller than in models which do not take adaptation into account. Tax rates needed to restore Pareto optimality are considerably smaller than in comparable models where adaptation effects are absent. Our conclusion is that adaptation (or behavioral) responses to damage are important for environmental policy design, are not discussed in the literature, and are worthy of more study.

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