economic consequences of weather, the

Households in the United States and a number of other wealthy nations have been migrating to places with nice weather. This likely reflects an increase in the relative valuation of the weather's direct contribution to household utility. Several different amenity explanations are discussed that can account for the increased valuation and ongoing move.

Introduction

> A cloudy day or a little sunshine have as great an influence on many constitutions as the most recent blessings or misfortunes.
> Joseph Addison (1672–1719), English essayist, poet and politician

> Don't knock the weather. If it didn't change once in a while, nine out of ten people couldn't start a conversation.
> Kin Hubbard (1868–1930) American cartoonist, humorist and journalist

It is hard to find a research subject more important than the weather. From ice ages to epic floods to endless droughts to malarial heat to the present warming of the earth, human welfare has always depended closely on it. Less awe-inspiring but also important is that weather is a direct source of significant consumption. Nice weather underpins the enjoyment of most outdoor activities from picnics to sports games to beach days to an infinite set of other possibilities. The discussion that follows will focus primarily on this latter, consumption dimension of weather. While such a focus may seem shallow in the face of the significant challenges weather poses to humanity, those challenges do not negate the fact that normal weather variations – the sorts that have been experienced year after year by current and recent generations – continue to be a large source of consumption benefits.

The discussion below will argue that rising incomes in the United States and other developed nations have increased households' willingness to pay to live in a place with nice weather. As a result there has been a shift in population towards such places. Before we consider this consumption dimension of weather, however, a brief discussion of the weather's day-to-day contribution to production is warranted.

Weather as a production amenity

Agriculture is the industry that most obviously depends on weather as a productive input. This dependence is multidimensional in the sense that temperature, humidity, cloud cover and rainfall – each over the entire growing season – all matter. A large enough deviation by just one of these can be sufficient to seriously impair yields. To be sure, advancing agricultural science has allowed crops to thrive in a wider range of weather conditions. But even loosened, the constraints imposed by weather remain significant.

Of course, different agricultural goods thrive in different weather. But abstracting from heterogeneity, it is easy to see that farmland in places with weather most conducive to growing will be valued especially highly. Farmers, assumed to be mobile across locations, will bid up the price of productive farmland until the weather's expected contribution to profits becomes fully

capitalized into land values. The higher productivity of farms in ideal-weather locations simultaneously makes it possible to pay workers there relatively high wages while still attaining the profits that could be made elsewhere. Note that the farm workers in such high productivity locations are not necessarily any better off than mobile farm workers elsewhere. General equilibrium considerations imply that their higher wages will be offset by higher prices for non-traded goods such as housing.

As with agriculture, the weather serves as a productive input into numerous industrial processes. Gunpowder, macaroni, tobacco, gum and chocolate are among the many products whose production requires constant, low humidity. Inside weather conditions are thus an extremely important productive input. Of course, in present-day developed countries, inside and outside weather are typically disconnected. But prior to air conditioning and central heating, inside weather depended closely on outside weather. Thus Oi (1997) argues that the spread of workplace air conditioning underpinned the rise of manufacturing in the south of the United States.

Nice weather also turns out to be empirically correlated with very-short-term stock market returns (Saunders, 1993; Hirshleifer and Shumway, 2003). Specifically, daily measures of sunshine in cities that host major stock exchanges are positively correlated with daily returns on those exchanges. In this case, weather's contribution is potentially productive only for day traders with very low transaction costs. The hypothesized mechanism is that nice weather uplifts traders' mood and optimism. Such a mechanism has much more the flavour of a consumption amenity than a productive one.

Weather as a consumption amenity

Just as weather's contribution to production puts upward pressure on the price of land and of housing, so too does its direct contribution to household utility. But as a consumption amenity, weather puts downward pressure on wages rather than upward pressure.

The expected correlations from weather's role as a production amenity and as a consumption amenity derive from the compensating differential framework (Rosen, 1979; Roback, 1982). An economy is assumed to be made up of a number of geographically distinct labour markets where households live and work and firms produce. The labour market locations may differ from one another with respect to numerous exogenous production and consumption amenities such as proximity to navigable water, access to natural resources, low risk of natural disasters, and – in a multidimensional sense – the weather. Production and consumption amenities may also be endogenous, for instance if increasing returns to scale lower input costs or expand the variety of consumer goods. The assumed high mobility of firms implies that they must be at least as profitable in their present location as they would be anywhere else. The assumed high mobility of households implies that they must derive at least as much utility in their present location as they would anywhere else.

The key to the compensating differential framework is that prices – in particular for land, labour and housing services – adjust to equate profits and utility across the numerous locations. In locations with high production amenities, firms are willing to pay higher prices for inputs, including for labour. These higher input prices are required to lower what would otherwise be higher profits than could be achieved from locating elsewhere. Similarly, in locations with high consumption amenities, households are willing to accept lower wages and pay a higher price for housing services. Such

households thus trade off lower tangible consumption of market goods for higher intangible consumption of amenities.

The empirical implementation of this model typically focuses exclusively on households and consumption amenities rather than firms and production amenities. The reason is the difficulty of observing the full range of firm input prices. Notable exceptions include Gabriel and Rosenthal (2004) and Chen and Rosenthal (2008), which treat housing service prices as a proxy for nonlabour input prices.

For households, the most common empirical methodology is to separately regress micro data of household income and a proxy for housing service price on respective vectors of attributes meant to control for differences in human capital and differences in the quantity and quality of housing services. The residuals from these regressions can then be regressed on location-specific attributes, including weather. Summing the extra annual housing service cost implied by a coefficient on a locational attribute in the housing regression with the lost income implied by the coefficient on the same locational attribute in the income regression gives the marginal consumption that a household forgoes to obtain a small increase in that local attribute.

Estimated compensating differentials for weather attributes from implementing this methodology tend to be extremely large. For example, the valuation per representative household for one extra sunny day over the course of a year is somewhere from US$21 (at 2005 prices) to $36. The midpoint of this estimated range implies an aggregate valuation of $26 million per year for a metropolitan area with a population of 2 million. Over 30 years using a three per cent discount rate, the implied net present value is $560 million. Whether households really require such a huge transfer to accept just a single extra cloudy day per year seems questionable. Other estimated weather valuations include one less rainy day over the course of a year, $36 per household; one less inch of precipitation, -$63 to $37 per household; and one inch less snow per year, $33 per household (Blomquist, Berger, and Hoehn, 1988; Gyourko and Tracy, 1991; Stover and Leven, 1992).

Heterogeneity of household preferences suggests that these estimates may understate the consumption benefits from weather. With heterogeneity, it is no longer necessary that all households be indifferent about where to live. The distribution of wages and house prices across locations that clears the labour, traded goods, and housing markets will be driven in large part by 'marginal' households, who tend to value consumption amenities by less than average. 'Inframarginal' households, in contrast, tend to value at least some consumption amenities highly. In order to live in a location where such amenities are abundant, inframarginal households are willing to accept a lower wage and pay a higher housing-service price than is actually required. Hence they enjoy a surplus that is missed by the compensating valuations above.

An even bigger empirical challenge to valuing weather and other consumption amenities is the difficulty of controlling for individual-specific and house-specific characteristics. A low wage may represent compensation for amenities, but it also may represent low human capital. A high expenditure on housing may compensate for high amenities, but it also may reflect a high quality and quantity of housing services being purchased. The characteristics typically used as controls when estimating the wage compensation include age, experience, education, sex, industry and occupation. For estimating the house price compensation, typical controls include rooms, bedrooms, units in structure, and appliances. These sets of attributes miss substantial sources of individual and housing-unit variation. Probably

most important for present purposes is the difficulty of distinguishing between high amenities and low human capital. The sorting of human capital across metro areas suggests that unobserved human capital characteristics may be correlated with the weather. The consequences of not sufficiently controlling for individual and housing service characteristics are evident in quality-of-life rankings of metro areas based on compensating differentials, which tend to contrast sharply with subjective rankings (Rappaport, 2008).

A complementary quantity approach to the compensating differential literature's price approach explicitly models population, capital inputs, land and housing supply. As is intuitive, high levels of consumption amenities attract households to a location, resulting in higher population and population density. (Henceforth, I shall make no distinction between the level of population and its density.) The higher population in turn supports the higher housing prices and lower wages of the compensating equilibrium (Haurin, 1980; Rappaport, 2008).

The seemingly obvious empirical implication of the quantity approach is to regress a cross-section of local population on exogenous local attributes such as the weather to infer whether such attributes are an amenity (with respect to either production or consumption). However, the extremely high persistence of local population implies that the correlation of population with an attribute might reflect an amenity contribution in the distant past that no longer exists. Instead, a cross-section of population growth rates can be regressed on the exogenous attributes. The resulting coefficients can be interpreted as reflecting the accumulation of past changes of the attributes' amenity contributions (Mueser and Graves, 1995; Rappaport, 2007). In other words, a positive partial correlation between population growth and a particular attribute suggests that the attribute's amenity contribution increased – becoming either more positive or less negative – in the intermediate past. The high persistence of population growth in the United States suggests that the 'intermediate past' probably reaches back at least several decades (Greenwood et al., 1991; Rappaport, 2004; Glaeser and Gyourko, 2005).

Empirically implementing the quantity approach establishes that population growth in the United States has been highly correlated with nice weather. Growth has been fastest where winters and summers are mild and the number of rainy days is moderate. The quantitatively strongest relationship, robust to numerous controls, is a positive quadratic correlation of growth with winter temperature. For the period 1970 to 2000, increasing January temperature from one standard deviation below its sample mean to one standard deviation above its sample mean (from 29°F to 54°F) is associated with faster growth of 1.3 per cent per year for US counties (Rappaport, 2007). Miami's temperature in January implies expected annual growth that is 3.4 per cent faster than that of US counties with mean January temperature. For comparison, the mean population growth rate of counties over this period was 0.9 per cent per year.

Population growth is negatively correlated with summer temperature and humidity (controlling for winter temperature, and robust to the inclusion of numerous other attributes). An increase in July heat index from one standard deviation below its sample mean to one standard deviation above its sample mean (from 87°F to 109°F) is associated with slower growth of 0.5 per cent per year. An increase in relative humidity from one standard deviation below its sample mean to one standard deviation above its sample mean (from 56 per cent to 75 per cent) is associated with slower growth of 0.9 per cent per year. Miami's temperature and humidity in July imply expected annual

growth that is 0.7 per cent slower than that of counties with mean heat and humidity.

Finally, population growth is characterized by a negative quadratic partial relationship with the number of rainy days. Increasing the number of rainy days by one standard deviation (25 days) above the mean (94 days) leaves expected population growth essentially unchanged. But increasing rainy days by a second and then a third standard deviation slows growth by 0.3 percentage points and then an additional 0.6 percentage points. For Seattle, with an average of 182 rainy days per year, annual expected population growth is 1.3 percentage points lower than that of a location with mean annual precipitation.

The weather accounts for a very large share of the variation in local population growth rates. The four weather variables just discussed, entered linearly and quadratically, along with annual precipitation entered similarly, can account for 27 percent of the variation in US county population growth from 1970 to 2000. This is only slightly less than is accounted for by dummies for each US state. For metro areas, winter weather alone accounts for 44 percent of the variation in growth from 1950 to 2000.

Results similar to those above hold for a number of nations, for a number of geographies within them, and for a variety of time periods. Similar partial correlations of growth with weather characterize US metro area growth from 1950 to 1980 (Mueser and Graves, 1995). In Europe, nice weather has been a major driver of population flows from 1980 to 2000 within countries, although not across them (Cheshire and Magrini, 2006). And net migration among Japanese prefectures from 1955 to 1990 was negatively correlated with a measure of extreme temperature (Barro and Sala-i-Martin, 1995).

The partial correlations strongly suggest that the amenity value of nice weather increased beginning at some point in the intermediate past, via either consumption or production. If the former, such places became inherently more desirable as the marginal utility from nice weather rose relative to the marginal utility of private consumption. If the latter, nice-weather places became more desirable because firms there could pay relatively higher wages.

The quantity framework allows for numerous explanations, many complementary, of the empirical migration to nice weather places. The common element of these explanations is that they posit a change in the valuation of some aspect of weather's amenity contribution, or else a change in the valuation of an amenity correlated with weather. One such explanation is that the approximate six-fold rise in per capita income over the course of the 20th century lowered the marginal utility from the consumption of private goods and services and so increased the quantity of these that households were willing to forgo in order to live in a place with nice weather. Consistent with this consumption amenity explanation, Costa and Kahn (2003), using the compensating differential framework, estimate that a representative household's valuation of enjoying the weather of San Francisco rather than that of Chicago increased more than fivefold between 1970 and 1990.

This rising income explanation for the move to nice weather might intuitively, but incorrectly, be understood to depend on weather's being a luxury good. In fact, it depends only on there being sufficient complementarity between weather and private consumption in the household utility function. Even with a homothetic utility function over private consumption and weather, an increase in income requires a sufficient increase in the valuation of nice weather to dissuade people from moving. More specifically, if the elasticity of substitution between private consumption and weather is exactly 1 (Cobb Douglas), wages and house service prices can adjust to

maintain a spatial equilibrium without any population movement (Rappaport 2009). Essentially a rise in the compensating price of nice weather can exactly cancel an income-driven increase in demand for nice weather. But if instead the elasticity of substitution between weather and private consumption is less than 1, the income-driven increase in demand is stronger and the larger required offsetting price increase can be supported only if more people move to nice-weather places, thereby driving up housing prices and driving down wages to their general equilibrium values. Conversely, an elasticity of substitution greater than 1 will cause the increase in demand for nice weather from increasing incomes to be somewhat weaker. In this case, the required increase in the compensating price is too low to be sustained without some movement away from places with nice weather. Intuitively, a broad, productivity-based increase in wages across all locations can increase the utility cost from not being where wage rates are highest.

A first alternative amenity explanation, based on production, is that the shift to nice weather reflected the movement out of the agriculture and manufacturing sectors. As the share of the labour force employed in agriculture fell from 36 per cent in 1900 to 12 per cent in 1970 to 2 per cent in 2000, the productive amenity contribution of weather to the marginal product of labour averaged over all workers probably decreased greatly. Hence the valuation of weather attributes directly increasing utility *relative* to the valuation of weather attributes conducive to growing would have increased. More recently, as the manufacturing share of employment fell from 25 per cent in 1970 to 14 per cent in 2000, the opportunity cost of moving within the United States from places with perceived less nice weather has probably fallen. One reason is the concentration of heavy manufacturing in the US Midwest, in part due to the proximity of raw materials and notwithstanding winters that are colder and summers that are hotter than many US households desire.

While the declines of agriculture and manufacturing surely contributed to the move to nice weather, they are unlikely to be the main causes. The partial correlation of population growth with nice weather is mostly unaffected by the inclusion of extensive controls for agriculture and other industrial structure. Moreover, the largest part of the move out of agriculture was over by 1970, which is the start date for many of the growth correlations reported above. Conversely, the move to nice weather began in the 1920s, when manufacturing employment was still growing vigorously.

A second alternative amenity story, based on consumption, is that the move to nice weather in the United States reflected the increased mobility and prosperity of the elderly. Rather than the population as a whole, it was primarily the elderly who increased their valuation of nice weather as it became part of their locational choice set. The increase in choice set followed from numerous trends, including the passage of Social Security (pensions for the elderly), increased longevity, and falling transportation and communications costs. Certainly, some warm-weather states such as Florida and Arizona have attracted a disproportionate number of elderly residents from elsewhere. But the strength of the partial correlation of population growth with nice weather is nearly the same for working-age individuals as it is for seniors. Moreover, the move to nice weather began long before the large increases in senior longevity and prosperity.

A third, related, amenity explanation is that for a broad swathe of the US population, mobility costs fell over the course of the 20th century. High moving costs allow for the possibility of rents for those residing in nice-weather places, with the negative compensating differential settling lower (in absolute value) than it would be with free mobility. To the extent that

mobility increased – for example, due to falling transportation and communication costs – nice-weather places would have grown disproportionately fast until they reached their free-mobility equilibrium. While this explanation has intuitive appeal, the extent to which mobility increased is unclear. The state-to-state gross migration rate was approximately flat from 1947 to 1975, then fell slightly through 2000.

A fourth alternative consumption amenity explanation for the move to nice weather is that it was caused by air conditioning. Air conditioning ameliorated the disamenity of hot and humid summer weather, which is correlated with warm winter weather. Hence households no longer needed to be compensated as much to live in hot and humid places, which in turn should have caused a shift in population towards such places. Doubtless there is some truth to this hypothesis, as many of the US metropolitan areas that grew most rapidly from 1950 to 2000 have summer weather that would seem insufferable without air conditioning (for example, the daily high heat index in July for Austin, Texas averages 118°F). However, the move to nice weather began decades before the widespread diffusion of air conditioning. Moreover, the negative partial correlation of population growth with summer heat and summer humidity is exactly the opposite of what air conditioning is expected to cause. Also tempering the air conditioning explanation is the extremely rapid growth of coastal southern California, where summer weather is relatively mild.

An alternative, nonamenity explanation argues that the correlation of population growth with nice weather is largely a coincidence. Glaeser and Tobio (2008) conclude that the post-war movement to places with nice weather arose from faster productivity growth in nice-weather places accompanied by a high elasticity of housing supply there. The latter was due to some combination of plentiful land and minimal government restrictions on building. The conclusion that weather was not an important driver of the population move to nice weather follows primarily from wage and house price compensating-differential regressions using data from the 1950 through 2000 decennial censuses. These regressions suggest that wages rose quicker but house prices rose slower in places with nice weather than elsewhere. Both of these comparative growth rates suggest that households' relative valuation of nice weather was decreasing over this period.

Certainly, the convergence of productivity in the US South to the national level was an important aspect of the rapid growth of many nice-weather places (Barro and Sala-i-Martin, 1991, 1992; Caselli and Coleman, 2001). But in the absence of any increase in amenity valuation, the relatively high density and congestion that have come to characterize many nice-weather cities would require productivity there to surpass its level elsewhere, not just converge to it.

Similarly, a relatively elastic housing supply is certainly a necessary condition for the rapid growth that was sustained over 50 years by a number of nice-weather metro areas. In the quantity model described above, the house supply elasticity governs the magnitude of the growth response to a change in amenities. But the impetus for the growth is solely the amenity change. Elastic housing supply, on its own, is not sufficient. Many sparsely populated and declining metro areas throughout the US Midwest and deep South also have plentiful land, light regulation, and in many cases an excess supply of existing buildings.

An additional consideration is the generic unreliability of the compensating differential methodology. The estimated rising wages by Glaeser and Tobio (2008) in nice-weather places may partly reflect an upgrading of unobserved human capital. The increase in the average skills of workers in

such metro areas may have been faster than elsewhere. For example, workers who moved to nice-weather places may have had higher skills on average than the skills of workers who already lived there. And slower-than-expected house price growth might reflect that the (negative) compensation for nice weather is being paid, in part, by longer commutes, increased traffic, and other sorts of metro area congestion.

Conclusions

The conclusion that households are shifting towards places with nice weather, at least in the United States, is not very surprising. Indeed, the US business magazine *Forbes* parodied some of the research cited herein on the population shift to nice weather with the headline, 'Duh!' (Kellner, 2004). Much more important is why households are doing so. The explanations above together suggest that rising incomes caused individuals to sufficiently increase their valuation of weather as a consumption amenity so as to require a shift in population towards nice weather places. For the increase in valuation to be sufficiently strong to cause this, weather must have been a complement to private consumption rather than a substitute. The shift towards nice weather was likely reinforced by the change in industrial composition away from agriculture and manufacturing, the increase in productivity throughout the southern United States, the spread of air conditioning, and the increasing mobility and financial security of seniors. Lastly, a high elasticity of housing supply in many nice-weather places implied that the population influxes required to support the increased valuation were quite large.

An important implication of the income result is that valuations of other local consumption amenities are likely to have increased as well. While local governments may be unable to affect their local weather, they may want to consider increasing the supply of other consumption amenities in its place.

A last question is whether the increasing valuation of nice weather and the shift in population towards it are likely to continue. Unambiguously, a continuing increase in income will cause a continuing increase in the valuation of nice weather. For the actual *movement* to nice weather to continue, the increase in valuation must be sufficiently large that it cannot be supported by the existing distribution of population across locations. With sufficient complementarity between weather and private consumption, theory suggests that the move can continue forever, though at a diminishing pace (Rappaport 2009). The increasingly swollen populations of many nice-weather places put downward pressure on their abilities to elastically supply housing and to mitigate other sorts of congestion. As housing supply becomes less elastic and other sources of congestion rise, a smaller increase in population can support a given required increase in compensation for local amenities. Consistent with a diminishing shift, decade-by-decade regressions show that the move towards nice weather peaked in the 1970s, and then slowed in each of the 1980s and 1990s.

Acknowledgements

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See also

compensating differentials;
climate change, economics of;
systems of cities;
housing supply;
urban environment and quality of life.

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