Introduction

The world is becoming more and more urban, and since 2008 the majority of people now live in urban areas (United Nations). The rapid growth of cities poses a number of important questions such as, how can cities be numerically evaluated? and how can cities best use available data to grow sustainably? In order to evaluate the success of a city we have created an index that takes into account environmental, economic, and social factors to give a rough idea of how well the city is doing and where it can improve most. This index was calculated for two cities on different continents: Colorado Springs, Colorado, United States, and Wellington City, New Zealand. As a case study, the growth plans of the cities were analyzed in terms of the ten principles of smart growth and the index. Then, using these principles, the results from the index, and other numerical indicators, criticisms and recommendations for the growth plans of each city were developed.

Part I: Creating an Index

The task of creating a number to represent the overall well being of a city is made difficult by the multitude of factors that influence the quality of life for its citizens. To simplify the problem, the well being of a city was broken down into three categories: Environment, Equity, and Economic. A sub-index was created for each of these categories, which were then averaged to calculate an overall index.

Economic Subindex

Although there are many factors that influence the economic health of a city, the unemployment rate is the most direct and easiest to measure. In fact, over 70% of economic activity in the US is from consumer spending(World Bank), which is heavily dependent on employment.

Since a higher economic subindex should represent a more desirable state, the unemployment rate (UR) had to be mapped to a value between 0 and 1. One simple way to do this is to use $I_{Econ}=1-UR = Employment\ Rate$. The flaw with this approach, however, is that it does not preserve the relative differences between two rates. For example, if City A has 3% unemployment and City B has 6% their scores would be 0.97 and 0.94, respectively,

meaning City A's score would only be about 3% better in comparison to City B, even though it had 50% less unemployment. Unemployment rates tend to fall within a fairly small range, even during a large economic downturn (the unemployment rate was only 10.2% at the peak of the most recent recession, compared with 4.7% today (US Bureau of Labor Statistics)). As such, a mapping had to be chosen that was very sensitive to changes in the 0% to ~10% range. In order to do this, the Economic Index was calculated by taking $I_{Econ}=e^{-2*UR}$. This equation allows for measurement of unemployment in a way that can be combined with other indices while still accurately reflecting the relative differences between the employment rates for different cities.

Equity Subindex

The equity index used in our greater city index is based on the GINI score. To avoid having the equity scores fall within too small of an interval the sub-index takes into account the fact that the vast majority of GINI scores fall within a range of approximately 0.5. This is done by using the current upper and lower bounds for the GINI score to regulate the equity sub-index score. The equity sub-index was calculated using the equation $\frac{0.63-GINI}{0.63-0.16}$. 0.63 and 0.16 are the highest and lowest GINI scores present at a national level in the world today (Index Mundi). This equation ensures that the relative differences in equity between cities are preserved when this index is combined with the other indices. The downside to this method of measuring inequality is that it is based solely on the GINI score for a given city, and is thus subject to the same pitfalls as the GINI coefficient when measuring inequality. The GINI coefficient is a relative measure that only measures income inequality, and thus may not capture a comprehensive picture of inequality in a region. In particular the GINI coefficient may still be fairly high even as other measures of equity may appear positive. This has been shown in some studies of mobility of the United States, where it has been shown that mobility stays fairly constant even as inequality increases (Chetty). However, it has been shown that GINI does correlated negatively with mobility, and thus equity as well, when analyzing across nations (Chetty). Despite potential problems with the GINI score, it is the most widely available indicator of inequality.

Environmental Subindex

Although there are many influences that a city has on its and surrounding environments, there are a few measurable factors that are unique and important to cities. The first is the amount of green space. Unlike rural or suburban settings, cities have to make optimal use of extremely limited land, so public parks and other green spaces are often lacking. However, there have been many demonstrated effects of having substantial green space in cities. Green space within a city is important for both ecological reasons and social reasons. In an increasingly urban world, green spaces provide many plants and animals with crucial habitats. In addition, trees and urban forests have been shown to reduce surface temperatures. Especially given the problems of urban heat islands, reducing the amount of radiation that reaches the surface is important. The urban heat island is an effect of the high heat capacity of concrete and asphalt. Even after the sun sets, cities remain warm from heat stored in building materials. The reduced temperatures may also reduce the risk of heat stroke and other temperature related illness (Wolch et. al) . Easy access to green space has been shown to significantly improve health, especially for people of lower socioeconomic status and youth (Maas et. al).

Theoretically, there is an optimal amount of green space in any given city. However, this is a partly subjective and nearly impossible number to calculate given available data. Therefore, for the purpose of indexing it was assumed that more green space is better. This assumption is justified since it is unlikely that a densely populated area would ever develop *more* green space than it needed. Simply using the percentage of green space in a city would yield an index between 0 and 1, but it would also result in almost any city having a very low green space index in comparison to other indices. To adjust the range of possible scores to a more relevant interval, the percentage of green space in a city was compared to the percentage in Moscow, which has the highest of any major city at 54% (World Cities Culture Forum)**.** Additionally, it was assumed that green space has declining returns, meaning that the first few increases in green space would have a larger impact than increases on an already large park system. This assumption seems reasonable given that many of the benefits of green spaces result from the health benefits of exercise. As such, it seems that if an individual already has a park near them that adding another would substantially change their activity level. With these desired behaviors in mind, the green space index was calculated with $I_{GreenSpace} = \sqrt{\frac{\%green\ space}{0.54}}$

The other part of the environmental subindex was based on measuring pollution. Although there are many types of pollution, air pollution can be broadly broken down into two groups, PM10 and PM2.5. PM10 is the number of μgrams per m^3 of particulate matter with a radius under 10 microns. Similarly, PM2.5 is the number of μgrams per m^3 of particulate matter with radius under 2.5 microns. The main deciding factor between the two possible measures was the availability of data, PM10 was the most readily available. The fact that PM2.5 is not measured explicitly in the creation of the environmental sub index is unlikely to be a problem, however, because PM2.5 is a subset of PM10, it is being indirectly measured. Again, the annual average PM10 count needed to be standardized to a value between 0 and 1, with 1 indicating the lowest pollution. The US Government has an air quality scoring system that takes into account the prevalence of various pollutants and calculates a score. These scores fit into 4 different groups. By looking at which ranges of PM10 fit into each group, we were able to index the PM10 annual average was mapped to a value between 0 and 1. For example, if a city's PM10 annual average put the AQI in the best group, then it would receive a score between 0.75 and 1, whereas if it was in the next group, it would receive a score between 0.5 and 0.75. Within each group, the exact score was assigned linearly. For example, if a city had a PM10 average that put it in the 50th percentile of the range for the worst group, then it would get a score of 0.125.

The pollution and green space indices were simply averaged to calculate the overall environmental subindex.

Results/Discussion

As a case study, Colorado Springs, Colorado in the United States, and Wellington, New Zealand were chosen for more in depth analysis. Below are the values of the subindices and final index for each city:

	Environment			Equity	Econ	Final Index
City	PM10	Green Space	Combined	Gini	Unemployment	
Colorado Springs	0.89	0.43	0.66	0.38	0.91	0.65
Wellington	0.94	0.38	0.66	0.68	0.86	0.73

Although Wellington has less green space, it significantly outperforms Colorado Springs in every other measure, bringing its score up to 0.73 compared to Colorado Springs' 0.65

When creating this index, there was an initial impulse to include as many indicators as possible. However, it was decided that keeping the index simple would be better for a number of reasons. The first is the availability of data. All the statistics used in the index are easily found for most major and mid sized cities. The second is comprehensibility. Creating an index that is excessively complex makes it nearly impossible to predict the impact of possible policy action. Finally, the reality is that the health of a city is so complex that no one number can accurately represent it while still preserving nuance. As such, it made sense to use a simpler index. These issues are discussed in depth in the Analysis Section.

Part II: Evaluating Current Growth Plans

Colorado Springs

Expectations/Projections:

Although Colorado Springs is growing quickly, it is not growing as fast as other cities in the region, most notably Denver (US Census Bureau). In Colorado in general, population growth has vastly outpaced housing capacity growth, most visible in Denver where housing is becoming harder to find. The increasing cost of living and rent in Denver, much higher than that of Colorado Springs, means that in the future there may be more people living in Colorado Springs and commuting to Denver, or going to Colorado Springs to shop. If these projections pan out then there will be a substantial increase in tax revenue, despite the fact that many will be spending a significant amount of time using the services provided by the

city of Denver. With this in mind, Colorado Springs has to address the question of how to most effectively rebuild the services that were cut due to declining budgets, and which new programs and services to start.

Growth Plan:

Colorado Springs has released a strategic growth plan to bring the country into the city into the next decade. The plan lays out a series of goals that it hopes will help increase economic growth, and improve the quality of life in the city so that it can have a more prosperous future. The plan released by the city is lacking in specific details, but the aspirational nature of the plan allows for an inspection into the planning philosophy that the city seeks to implement as it grows. Colorado Springs has divided its goals into four categories. These categories are "promoting job creation," "investing in infrastructure," "building community & collaborative relationships," and "excelling in city services."(City of Colorado Springs).

The first section of the Colorado Springs growth plan centers on job creation. The city plans to streamline business regulation, and update old outdated policies. The city also plans to leverage its gubernatorial power to incentivize the revitalization of a number of communities, and increase the interconnectedness and interdependence of the city. By supporting community initiatives, and promoting the image of the city, it hopes to attract more business to the region. The primary action the city government is planning to take to insure strong future growth is by targeting specific areas within the city for renovation and revitalization. Through the use of EOZs (Economic opportunity zones), and improving public safety the city government aims to pinpoint economic, and community growth in specific regions in order to ensure broad growth throughout the entire city. The EOZs are particularly salient when it comes to this topic, as the planning behind these zones is much more concrete in comparison to the rest of the city growth plan. Each region that is designated as an EOZ receives a fairly comprehensive plan for economic growth that specifies exactly how the city wishes to reinvigorate the area that include a list of goals as well as outcomes that are to be avoided.

Secondly, Colorado Springs aspires to improve the infrastructure of the city in order to increase economic growth, and accessibility. The city has yet to propose specific guidelines as to how, and where they plan to improve infrastructure, but the city has stated that it

plans on emphasizing technological infrastructure, in tandem with more traditional infrastructure like roads. The city plans to improve the connectivity of the city's trails, sidewalks, and facilities. The city also plans to focus the infrastructure improvement in the aforementioned EOZs to ensure a diffuse distribution of growth and general improvement in the city.

Thirdly, the city wishes to expand community and civic engagement moving forward. To accomplish this the city plans on using a variety of different channels to engage the public. These will include the use of technology to directly reach out to citizens and ask for their input through surveys and other measures, as well as semi-annual meetings and volunteer groups. Colorado Springs is eager to improve community engagement by fostering inter community partnerships. These will work alongside efforts to decrease emergency response times, improve school access, increase the amount of affordable housing, and curb the number of homeless persons living in the city through collaborations with non-profits.

Lastly, Colorado Springs intends to cultivate a culture of consistent improvement. The city has indicated that it intends to accomplish this through a combination of technology and the promotion of the city's potential culture. The city also plans to increase the use of research when making impactful decisions about city planning.

The Colorado Springs growth plan may not be particularly definitive in its intentions, but the general nature of the plan allows for an evaluation of the city's growth plan in relation to the "smart growth" principles. The Colorado Springs Growth plan lacks any meaningful action to directly reduce urban sprawl, or improve the environmental conditions of the city, but it does do a great deal to address problems of equity and economic growth in the city. The city may have, however, be inadvertently addressing urban sprawl and the environment, by choosing to revitalize older, and more distressed communities, while expanding the connectivity of the city. The city's plans to boost economic development appear to be promising, but the lack of specific information on this subject leaves a great deal of uncertainty as to whether or not these plans will result in any substantial increase in growth. The use of EOZs is, however, an economic proposal well in line with the "smart growth" philosophy, but it is unclear as to how exactly the city will get developers to redevelop these regions, as the incentives are unclear at this moment. The growth plan for

Colorado Springs will likely make the most progress in combating inequity in the community, as it encourages community and civic engagement, alongside expanding access to affordable housing, and better treatment of the homeless. The plan does not address how power will be supplied to the city, and whether or not the city plans to expand the use of renewable energy to power the city. Colorado Springs may make some minor gains in environmental sustainability by expanding sidewalks and bike paths, as well as reusing depressed parts of the city rather than developing anew, but the city has largely failed to address issues of the environment. The exact effects of the growth plan on the index is difficult to assess, but the proposed actions would almost certainly boost the economic and equity subscores.

Criticism/Recommendations

There are a number of flaws and potential shortfalls with Colorado Springs growth plan. The first is, as noted above, that the plan lacks in specific projects of policy action that the city will take in order to make the goals of the growth plan a reality. Although the growth plan has utility as a guiding document to frame and guide the legislative process, without long term planning, the many specific actions that are required for smart growth are subject to political, economic, environmental, and other factors that are inherently difficult to foresee and plan for. Therefore, it would be advisable for Colorado Springs to create a list of possible projects with a bottom up approach. Specifically in the areas of transportation, urban revitalization, and smart development of housing areas, Colorado Springs should take time to make a detailed and high resolution set of plans. For example, it could look into exactly what kinds of changes would make the core of the city more permeable to pedestrian and cycle traffic, how to make green space be available within walking distance of all residences, and how to best ensure mixed use of centrally located areas. One specific action that Colorado Springs could look into is the creation or incentivization for the creation of large buildings that can serve a number of purposes, such as providing office, retail and food service space.

Another issue, also noted above, is the lack of protections for surrounding ecology. One of the major attractions of Colorado Springs is its proximity to many outdoor recreational activities. The outdoors is the main draw for tourists who spent $1.97 billion in 2015 and generated $70 million in tax revenue for the Pikes Peak region (City of Colorado Springs), in

which Colorado Springs is the principal urban center. As such, preventing urban sprawl and limiting pollution is not only an environmental concern, but also an economic one. Planning environmentally is also a concern for equity, often the worst ecological environments in urban areas are in low income and minority neighborhoods (Liam & Hawkins)**.** Colorado Springs should focus on increasing the availability of green space and public transport for its most impoverished citizens while attempting to limit urban sprawl, both to curb the ecological footprint of the city and to ensure economic equality and stability in the future.

Another problem with the Growth Plan is that it does very little to address one of the biggest problems Colorado Springs faces, homelessness. The homeless population grew 19.5% from 2015 to 2016, compared to a 8.5% growth in total population over the same time period (Pikes Peak Region United Way).Given that the homeless population is increasing over two times faster than the general population, Colorado Springs will have to take well defined and substantial actions to reduce homelessness.

The first step in this process is figuring out the causes of homelessness. The 2016 Point in Time survey, which collects information about homelessness in Colorado Springs, has found that the percentage of shelterless people who arrived from a state other than Colorado went up from 17% in 2015 to 28% in 2016 (Pikes Peak Region United Way). This could indicate that the rise in the homeless population is in large part from people moving to Colorado Springs in search of economic opportunity. With this in mind, some actions that Colorado Springs could take are: increasing vocational and life skills training opportunities for the homeless, making environments conducive to job growth, and possibly creating forward thinking programs to hire more homeless into city jobs.

 As with other cities, veterans make up a disproportionately large portion of Colorado Springs' homeless population (Pikes Peak United Way). With veterans, issues of mental health, addiction, and reintegration into society are some of the largest barrier to ending homelessness. Programs should be created to address these issues in detail.

One possible solution is creating a robust "housing first" program. Housing first programs are relatively new, focusing on getting homeless people into their own residence as soon as possible. As opposed to the more traditional model which generally makes subjects go through "levels" of housing with the ultimate goal of independent living, housing first programs primarily focus on getting subjects a shelter that they can claim ownership of.

Housing first programs have shown great success not only in long term reintegration of homeless, but also in terms of reducing the burden of homelessness on taxpayers. A pilot program in Colorado found focusing on housing first reduced the number of instances and costs of inpatient care, emergency detox operations, and imprisonment for test subjects (Perman & Parvensky). Colorado Springs could build housing in line with smart growth principles that could serve as the foundation for a housing first program to end homelessness.

Ending homelessness, aside from the direct benefits, has externalities that will help the environment, economy and equality. Addressing this issue will prevent sprawl in the form of tent cities, raise property values, and provide a sense of social justice. As such Colorado Springs has to take time to develop a robust and detailed plan to address the growing issue of homelessness.

The final criticism of the growth plan is that it does very little to discuss how the new residential areas that will be needed to house the growing population will be designed. Rents are going up quickly, rising 9.4% from last year (Apartment List). The raise is mostly a result of the 8.5% population growth. Suburbs tend to be a nightmare in terms of smart growth principles, focusing on individual privacy at the cost of community cohesion and strength. The isolation of residential communities can be measured in a number of quantifiable ways. The first is the average walking distance between any two residences. Winding roads that try to simulate rural living often end up making communities difficult to traverse, and increasing barriers to participation in community events. Average walking distance from public open spaces is another important consideration, as well as the amount of open space per person. Instead of focusing on increasing the amount of green space owned by individuals, Colorado Springs should attempt to grow communities around large shared green and public spaces.

Wellington

Expectations/Projections

Wellington anticipates about 42,700 additional residents by 2043, which they will accommodate with the addition of 21,400 dwellings. They expect their population to get older, with 13.5% of the population over the age of 65, compared to 9.6% now. The action plan is grouped under the following 6 categories:

- transformational growth areas
- liveable and vibrant centres
- real transport choices
- housing supply and choice
- natural environment
- city resilience.

The growth plan tries to address possible housing shortages, while preventing urban sprawl, and making sure that suburban communities are vibrant. In addition, it moves to revitalize many "core" areas of the city by making them easier to access by public transport, more pleasant to be in, and increasing tree cover and footpath size. In short, the growth plan, at least in theory, addresses almost every principle of smart growth.

In order to turn the growth plan into a reality, the Wellington Government has released a Growth Plan Implementation Plan. This document contains an impressive level of detail about specific projects that will take place over the next decade and how they fit into the city growth plan.

A number of projects focus on roads in the densest parts of the city. Many involve widening footpaths by taking advantage of unused land while keeping the road width constant. In addition, these projects aim to plant a specific number of trees and make more dedicated bike lanes. If all of these road improvements were to be completed, it would significantly boost the amount of green space in the city while also making the core of the city a vibrant social hub.

In terms of transportation, the implementation plan aims to increase cycling routes, give busses priority in traffic while minimizing congestion, and reactivate many lanes. The city has laid out a number of locations, such as schools, office buildings, and businesses, and general zones that it wants to be connected through intuitive and usable bike paths. Although it already has many dedicated bus lanes, it thinks that increasing the number will

allow busses to run better, increasing ridership. There are many small lanes that are dead ends, or are simply too small for the average car. The city plans to turn these lanes into walking paths, thereby providing many miles of potential storefront, and also increasing the pedestrian permeability of the city.

Finally, there are detailed plans for revitalizing specific urban areas. Many of these plans involve the creation of buildings for many purposes. For example, one project involves making a large building that will have office space in the upper floors and space for stores and food vendors in the lower floors. By placing this building on the waterfront, they hope to create a place that people can work, eat and shop, and relax.

Although it is difficult to quantify the exact impact of Wellington's growth plan on the previously described index, this detailed agenda shows promising signs of smart growth in many categories. They plan to revitalize existing communities by refining roads to accommodate cyclists and public transportation, while converting insufficient ones into spacious walking paths accompanied by the addition of many trees and miles of storefront. These new shops will create many jobs, and the city's substantial presence in the fast-growing tech industry will continue to keep unemployment rates low in the future. The infrastructure developments will also create a safer environment for pedestrians and faster travel for those using public busses, which will encourage efficient means of transport and reduce pollution.

 The plan focuses on constructing and remodeling quality affordable dwellings that will attract a diverse population while limiting urban sprawl. These medium-density housing developments will be water and energy efficient, using renewable sources wherever possible and being resilient to earthquakes, which further exemplifies environmental smart growth. Creating multi-purpose buildings with office space, shops, and restaurants will foster a culture of social inclusivity that attracts people of different income levels and backgrounds. This will bring people of different social statuses together, potentially reducing the relatively small wealth gap that currently exists. It is clear that Wellington has considered smart growth in developing its expansion plan for the next few decades, and if executed successfully, each of the environmental, equity, and economic subindices as defined above will rise along with the population and prosperity of the city.

Criticism/Recommendations

Overall the Wellington growth plan appears to be fairly consistent with the ideals of "smart growth" the city may, however, need to take into account a number of other factors as well when implementing its growth plan going forward. Most notably the significant increase in the elderly population of Wellington may require a slightly different set of ideas to ensure the greatest possible quality of life in the city. The plan generally does a good good of confronting urban sprawl by increasing urban density, while simultaneously increasing connectivity within the city by further developing the bike paths and walkways in the city. By promoting social inclusivity and community interaction Wellington may be able to reduce inequality between those of different social statuses. Although Wellington may make note of the need for new domiciles and other buildings to be energy efficient it fails to make any assertions about how it will produce its energy in the future and whether or not it will emphasize renewable energy.

Conclusions/Discussion

Indexing Cities

We were able to successfully make an index that allows one to compare cities. Although the index can compare cities, it has limited use in developing and evaluating growth plans. This is because different cities care about different issues. For example, cities in developing countries tend to have very high inequality as the income demographics change rapidly, but this is not necessarily a problem. Since development necessitates inequality, it would be silly for a city in a developing country to decide to combat inequality instead of focusing on GDP growth. It is possible to make adjustments so that each sub index is adjusted for the situation that the city is in, but at that point, the index loses its value as a tool for comparison. What we can conclude is that if a city's index increases over time then the city is getting better, but, based on the index at any point, it is difficult to make recommendations without more information. Our, and indeed any index, provide a starting point that paints a very rough picture of a city, and enable different cities to be compared, but for in depth analysis consideration of other factors is critical.

To account for the lack of specificity of the index, we propose that many other factors be taken into account alongside those used in index formula. Among these we have two different formulas that can be used to estimate city density. The first is what we have labeled as the Sprawl Coefficient (or SC) which is defined as $\frac{Population * GDP}{City\ Area}$, such that a higher SC value signifies a more dense urban zone. The Sprawl Coefficient is designed to measure how spread out the population of a city is in relation to its wealth. This is done to ensure that impoverished but extremely densely populated regions are not score higher than wealthier regions with a higher quality of life. The Second measure of density is what we have termed the Transport Density (or TD) which is defined as $\frac{Total\ Number\ Of\ Roadway\ Intersections}{Total\ Distance\ Covered\ By\ Roads}$. This metric assumes that more dense urban zones will likely have a greater number of intersections per kilometer of road, as thus a higher TD score indicates a greater density. We also define a Walkability Coefficient (or WC) as $\frac{Total\ Distance\ Of\ All\ Pedestrian\ Paths}{Total\ Distance\ Covered\ by\ Roads}$. The WC is intended to give a rudimentary estimate of how walkable a city is, although we recognize that particularly in developing countries the WC may be less meaningful.

Results and Conclusions:

The index uses a set of commonly available economic, environmental, and social equity data score each city between zero and one. Through simple manipulations of the data the index was made to better reflect the realistic ranges of the data points selected. The index intentionally takes into account a small number of indicators in order to increase transparency, and to ensure that even cities with less data available could be indexed.

Using the calculated index and the ten principles of smart growth the growth plans of both Colorado springs and Wellington were analyzed and critiqued. It quickly became clear that without other information and data the index and the ten principles alone were not a sufficient basis for guiding public policy. The index does, however, remain a useful tool for quickly comparing cities, and tracking the general direction of their progress over time.

The Colorado Springs growth plan, although lacking in specific actions, provides a guiding framework for public policy that is in line with the principles of small growth. From this basis Colorado Springs develops a set of specific projects in line with the goals of the

growth plan to ensure that the goals of the growth plan become a reality. In addition great attention should be paid to the increasing number of homeless persons present in the city, and the lack of affordable housing in general.

Wellington by comparison provides a model city growth plan that effectively combines aspirational goals, and concrete planning and policy action. Its city growth plan is generally in line with the principles of "smart growth," and its city growth plan implementation plan provides extensive documentation on how specific projects of the next ten years will help the city to meet its stated goals.

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