# "From manufacturing belt, to rust belt, to college country"
# A Visual Narrative of the US Urban Growth[1]

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What has shaped the US urban landscape? Probably, different forces worked at different magnitudes, times and locations. In this paper, we develop a methodology to disaggregate some of the engines of US city growth over time and across space. To understand the results, we propose a visualization approach based on what we term *storyboards* which create an intuitive and dynamic narrative on the effect of several factors of urban success. This allows us to show that the role of growth engines greatly differs: the rise and decline of manufacturing was very localized; industrial specialization is counterproductive, particularly so in the 1990s; service sectors used to be a consumption amenity, but now serve as a production amenity; and highly educated cities unambiguously and increasingly attract firms in any part of the US. We also note that the arguments for our visualization and its lessons bear implications for vizualization in the social sciences beyond this particular example.

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## Introduction

What makes cities rise and decline? What attracts Americans to some cities, and drives them away from others? Policy makers, academics and the general public have tried to understand the engines of city growth. Yet, one single explanation may not fit all; more likely, some forces worked in some places, at some times. The purpose of this paper is to gain insight into which forces of growth were important at what time. Instead of proposing new forces of city growth, we propose a novel way to examine explanations of city growth. To that extent, we combine an economic model with a visual approach that interprets its output in a structured and intuitive way. This not only helps to analyze urban growth patterns, but also makes the causes of urban change more insightful to a non-technical audience.

Over the past decades, the urban landscape has changed substantially. The overall post-WWII urban growth pattern in the US shows decline until the 1970s, followed by a resurgence of the city afterwards. However, Rappaport (2003) shows that the aggregate changing pattern applied only to a limited group of cities for which population decline reverses over the period; most cities only experience either growth or decline. The Midwest attracted workers long ago, but cities near US coasts have fared better over the course of last century. In recent decades, cities like Detroit and Pittsburgh have seen population losses, while cities especially in the South, like Houston, Phoenix or San Diego, have dramatically grown. Yet other cities like New York, San Francisco and Seattle witnessed rapid growth in the 1990s, after years of sustained decline. Aiming to inform urban planners, and driven by the desire to understand how to create and attract jobs, understanding these urban changes in the US has become a central policy challenge over the last years.

One reason for city growth to vary over space and time is that jobs in cities change over time. Cities attract people because of their employment opportunities and productive benefits. Recent evidence precisely shows that workers become more productive in urban environments (Combes et al., 2012). Workers in large cities exploit the scale effects of their industries, thus securing more and better-paying jobs. Spillovers and pooled labor markets help cities thrive, and the industrial structure of cities may therefore be a large asset. Glaeser et al. (1992) show that specialization patterns have played a large role in urban economic growth. However, technological change has favored some industries over others, and international sourcing strategies have put pressure on offshorable jobs (Blinder, 1996). The manufacturing belt attracted many jobs with its extraordinary rise (Krugman, 1991; Klein and Crafts, 2012). But its decline into a rust belt has turned the industries into a liability for the hosting manufacturing cities (Flynn and Taylor, 1986), leaving them with low-skilled, often unemployed, workers. Instead, well-educated workers seem to have weathered the crises and globalization better. Technological changes have reinforced this process by favouring their jobs and wages over those of the lesser skilled (Autor and Dorn, 2013). Glaeser and Saiz (2003) show that much of the recent economic and population growth of US cities is associated with high-skilled workers.

Although jobs are relevant, they do not determine urban fortune completely: people also migrate because they like living in some cities better than in others. As people become more skilled and their income grows, "quality of living" gains importance and people increasingly seek out the large consumption options and amenities that cities provide (Glaeser et al., 2001). Cities offer restaurants and theaters, and a "mix of social partners" to attend them. In particular, colleges and universities do not only train highly skilled workers, but also serve as amenities in themselves: parents are attracted to cities that provide their children with a good education and people consider living next to more highly skilled individuals a desirable situation in itself. In addition, highly educated cities see less conflicts, less crime, and offer more luxury services, leading to a higher overall quality of life (Shapiro, 2006). In this respect, Storper and Scott (2009) point to a causality problem: do highly educated citizens attract yet more population, or do firms follow highly educated workers, in turn causing migration for jobs?

In this paper, we employ an economic model to discern the role of several of the above processes. Essentially, we investigate how phenomena like manufacturing and educated workers have left their traces in metropolitan land and labor markets. The most desired land typically has the highest prices, but we also consider whether workers are willing to take lower wages to live in a certain city, or whether firms locating in that city are prepared to pay workers higher wages. By relating different engines of growth to the land prices as well as to wages, we infer whether the potential growth engine made the city a more attractive location, and whether it attracted primarily firms or population. These effects can be calculated over time as well as over cities, yielding a bulk of results that may not be directly comprehensible.

Our approach to visualize the effects of several engines of growth helps solve two of the main challenges mentioned above: the issue of looking only at averages; and the issue of understanding whether jobs or people cause growth. Firstly, growth is not uniform over time or space, and graphical displays allow disaggregating these patterns. This helps to understand, for instance, how large manufacturing sector has attracted firms to coastal states in the 1980s, and driven them away from more central cities only some decades later. Secondly, by visualizing the rent and wage effects, we can discern whether engines of growth have predominantly attracted jobs to a city, followed by people; or have predominantly attracted people directly. For instance, we show how services were viewed by people as an amenity worth migrating to in the 1970s but, over time, the share of the service economy in a city has grown into a productive asset, attracting firms rather than people. A large share of college-educated population, by contrast, has contributed substantially to productivity in all US cities after WWII. Our results thus also show the use of our approach. Manufacturing changes nature from productive asset to push factor for citizens, and its effects vary by city. By contrast, college educated citizens seem to play a productive role across the country.

In a more general context, the exercise proposed in this paper can also be understood within a larger case for the role of visualization in the Social Sciences. As we demonstrate, visualization is an ideal tool to take results from sophisticated, mathematically-based analysis and present them in a more accessible and comprehensible way (Tufte, 1983). In particular, we believe visualization can act as vehicle to better communicate information to two non-technical audiences:

policy-makers and other stakeholders such as journalists interested in understanding economic mechanisms at work in cities and regions; and students in the classroom who are being introduced to the field but do not yet have all the analytical toolkit to fully understand the underlying theories. For the first group, accessing urban research that would otherwise go mostly unnoticed allows them to have a better informed view about issues on which they make relevant decisions; for the second one, visualization allows the student to engage with ideas and concepts relevant for his education at an earlier stage in his training, forming a more accurate picture of the real-world in his mind. This argument in favor of visualization has probably always been present, but we feel nowadays it is more timely than ever. As our society and cities move into a more data-centric world (Batty, 2012, Batty and Cheshire, 2012), it is important to ensure larger parts of the population can interact with some of these methods and results. Visualization thus can play a key role in bridging these two.

In the following, we first discuss our methodology. Since the underlying economic theory is quite established, we convey the intuition at a level of depth enough to be able to follow the rest of the paper, but we skip the mathematical apparatus. Section  presents the visualization approach we suggest to display the results of the model; Section  applies it to the main phenomena highlighted by the literature as drivers of urban growth; and Section  concludes with a reflection on the role of visualization in this endeavour.

## *Methods*

The methodology we employ assumes that engines of growth leave their traces in the land rents and wages of a city. These land rents and wages tell us who had the greatest desire (or dislike) to locate in the city. Land rents typically rise where land is in high demand, but considered jointly with wages, it can also be inferred whether businesses or people demand land. This helps identify, for instance, not only that large manufacturing sectors have made cities desirable, but also that it was mostly firms that were attracted to cities with large-scale manufacturing sectors. The spatial patterns in land rents and wages are sometimes called compensating differentials - because they reflect how much or little an individual or firm needs to be compensated to live in one city versus another. Named after Roback (1982), the methodology is not new (at all), and it has been used extensively, for instance to gauge the role of migrants (Ottaviano and Peri, 2006) or the quality of living in cities (Albouy, 2008). The novely of our paper is that we attempt to break down the aggregate statistic over space and time, allowing the role of manufacturing to play a different role in different cities at different times. Moving beyond an average statistic, we need visualization to convey our results.

The methodology boils down to examining how the phenomena of interest (say, a manufacturing sector) affect land values ($r$) and wages ($w$). The manufacturing sector might attract people, because it means many goods are cheaply locally available. The manufacturing sector thus exerts a (consumption) amenity effect, and migrants bid up land prices. However, the manufacturing sector can also affect the productivity of prospective firms through technological spillovers or scale effects. If the manufacturing sector improves productivity, firms bid up land prices to locate in the city.[2]

[2] We use the manufacturing sector as an example for the sake of illustration, but clearly, other engines of growth can substituted here.

To understand whether it is firms or people that bid up land prices, we need to look at wages. If people like the amenity value of the manufacturing sector, they migrate to the city with high rents, prepared to accept lower wages in the city. Rising rents and falling wages therefore suggest people value the amenity. If it is firms that bid up the land price in productive location, they can offer higher wages (and they need to, because workers have no other reason to migrate to the city). Thus if large manufacturing sectors are associated with high rents and high wages, the reason for locating in the city is high productivity. If cities with large manufacturing sectors typically have high rents and low wages, the reason people migrate to the city is that the manufacturing sector acts as a consumption amenity. The opposite is true if rents and wages in manufacturing cities are low. Land is not desirable but workers stay, taking lower wages: the large manufacturing sector must be driving away firms, not people.

The wage and rent effects of a manufacturing sector (or any other potential growth engine) show it contributes or stops city growth. These effects can be derived in an economic equilibrium model (e.g., Ottaviano and Peri, 2006), but since the results are well established, we only summarize them:

| effect on rents | effect on wages | type of force |
|---|---|---|
| + | + | productive amenity |
| + | - | consumption amenity |
| - | + | consumption disamenity |
| - | - | productive disamenity |

Below, we estimate the effects on rents and wages of different drivers of city growth. Using data from the US census, we run decadal cross-sectional regressions for US metropolitan areas. To allow for shocks in one location to affect the land market as well as the labor market, we run a seemingly unrelated regression. Using $X$ as a potential engine of growth (like the size of the manufacturing sector), we estimate:

$$\begin{aligned} \log r_{ct} &= \beta_{rt} X_{ct} + \varepsilon_{rct} \\ \log w_{ct} &= \beta_{wt} X_{ct} + \varepsilon_{wct}, \end{aligned}$$

where the subscript $c$ refers to the city level and $t$ is a time index. Inferring $\hat{\beta}_{wt} X_{ct}$ and $\hat{\beta}_{rt} X_{ct}$ from the regression gives the estimated contribution of (e.g.) the manufacturing sector to the rent and wage level in each individual city in a single year. For a given city, these contributions can vary over time for two reasons. Firstly, the effect of manufacturing, $\beta$ can evolve over time, and secondly the size of the manufacturing sector $X$ itself can vary over time. Thus, even if the role of manufacturing grows over time, the effect on the city can fall if its manufacturing sector is shrinking.

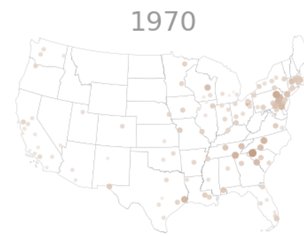
Our dataset stems predominantly from the Integrated Public Use Microdata Series (IPUMS). There are 281 metropolitan areas in the sample, and we observe workers in 1970, 1980, 1990, 2000 and 2010. We use average wages over all workers in the metropolitan area as a measure for the metropolitan wage level. For the land prices, we use the land rents reported by the same workers in the metropolitan area. We use four prime variables of interest: the size of the manufacturing sector, the size of the service sector, college education, and industrial specialization.[3] For the manufacturing share, we take the ratio of employees working in a manufacturing industry to the overall number of employees. Our education variable takes the metropolitan share of workers that has had college education or higher. For the industrial specialization index, we follow convention and calculate the Krugman index. It is calculated as $K = \sum_i^I |b_i - \bar{b}_i|$, where $i$ denotes the industry (of $I$ industries), $b_i$ is the local employment share of industry $i$ and $\bar{b}_i$ is the national employment share of industry $i$. A low specialization index points to an industrial structure that is very close to the national average, whereas a higher index indicates relative specialization.

[3] Our survey of urban growth engines is far from complete. To show the visualizations, we have focused on four popular explanations, but other possibilities include the effects of physical geography, social capital, institutions or the creative class (e.g., Henderson and Wang, 2007; Florida, 2002).

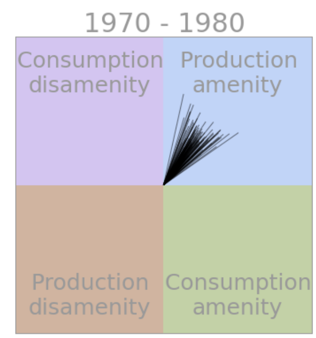
## *Visualization approach: a storyboard of urban evolution*

The model we have just outlined produces a substantial amount of raw output that cannot be interpreted in a direct way. In fact, for every combination of metropolitan area, year and variable, we have two estimates: one for the effect on rents and a separate one for the effect on wages. A simple "back-of-the-envelope" count yields 2,810 measures per variable (281 cities by 5 years by 2 coefficients) with potentially relevant information. Unfortunately, a clear understanding of this output in raw form is beyond the human brain capacity. Besides, the value of this information resides in the overall patterns that can be extracted from them, rather than in an individual analysis of every coefficient.

We propose a visualization approach that displays all the estimates and places them in context, allowing for intuitive comparisons and exploration. The main goal is to organize the model output in a way that invites the reader to understand it as a story in which alternative variables play different roles at different moments and places. The tool we rely on is a figure that represents the evolution of a single variable across space and time and that we call *storyboard*. A *storyboard* is fundamentally composed by two types of plots: snapshots and transitions. The snapshots are essentially geographical maps that show the model's results in a single year. These static pictures are connected by a transition plot that makes explicit the direction cities took from one period to the next. Snapshots and transitions are arranged chronologically, alternating one another, conveying the idea of time and evolution in a familiar fashion. The result of this is a figure that, just like a conventional storyboard, displays the sequence of events that occurred and connects them over time, making explicit the dynamic nature of the process they aim to portray. Before we introduce the full Figure, let us explain each of the two components in more detail with an example.




(a) Snapshot




(b) Transition

Figure 1: Elements of a storyboard plot (Example with manufacturing in 1970 and 1970 to 1980)

Figure 1 shows the snapshot of manufacturing in 1970. Throughout this paper, we use the following color coding: green denotes a role as consumption amenities (rising rents, falling wages); blue represents production amenities (rising rents, rising wages); disamenities are reflected in purple for consumption (falling rents, rising wages) and brown (falling rents, falling wages) for production. The brown color of the dots thus indicates that this variable acted as a production disamenity: firms were driven away from manufacturing-intense cities. This result fits with earlier results that suggest a decline in manufacturing after the WWII buildup and 1950s. To denote the scale of the effect, the intensity of the color as well as the size of the dots follow the magnitude of the rent and wage effects[4] - assuming that powerful sources of attraction raise the rents strongly as well. The map allows us to get an overview of how the intensity of this effect was distributed over space: for most cities, it is not very large, and most of the effects concentrate in the North East.

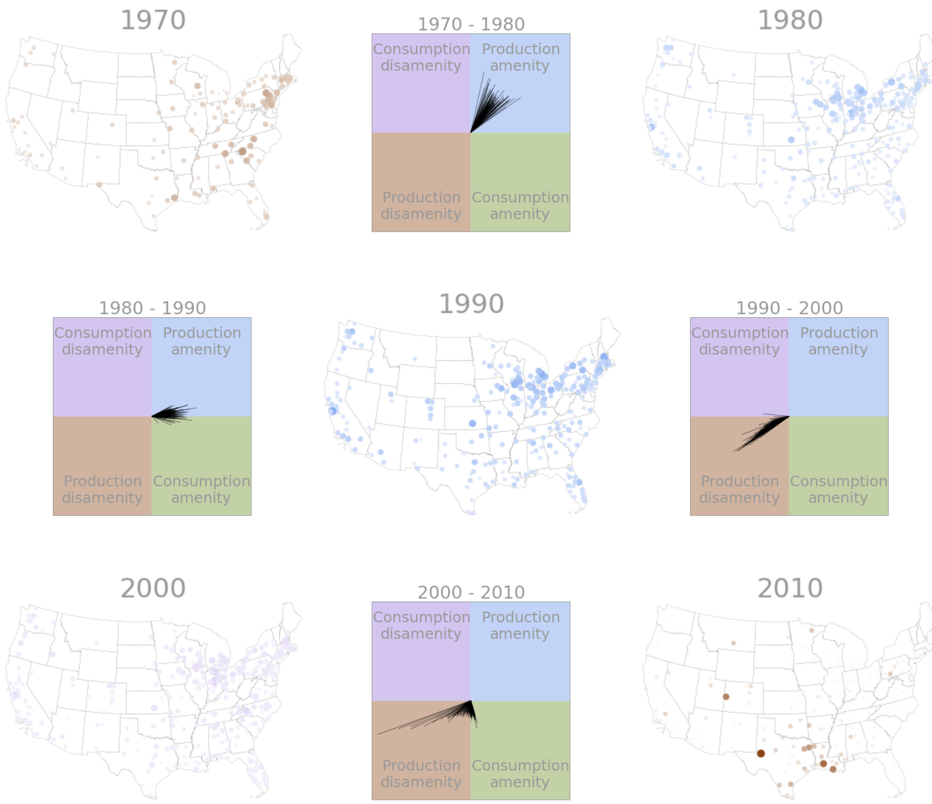
The transition from 1970 to 1980 is displayed in Figure 1. The main challenge in this plot is to convey the dynamics of cities from one period to the next. To solve this with a static figure, we borrow a concept from directional statistics. We summarize the movements of cities in the two-dimensional space of rent (X-axis) and wage (Y-axis) effects by displaying, for each city, the vector that connects the pair of effects from the initial year to that of the following one. The

[4] Strictly speaking, the value for both dot size and color intensity is a transformation of the length of the vector that goes from the origin (0, 0) to the coordinate marked by the rescaled rent and wage effects $(\bar{re}_{t+1}, \bar{we}_{t+1}) = (re_{t+1} - re_t, we_{t+1} - we_t)$. The terms $re_{ct}$ and $we_{ct}$ are the city-specific predicted effects on rents and wages, respectively, of our variable of interest ($X_{ct}$) in year $t$ from the regression described in Section 2.

attractiveness of this approach is that the direction of the vectors in this context carries a clear meaning for what happened in a city over the period analyzed. A joint positive change in the wage effect and the rent effect indicates a role change towards production amenities (upper right quadrant, in blue); while a joint negative change in the wage effect and the rent effect points to production disamenities gaining relevance (lower left quadrant, brown). A change towards consumption amenities is associated with lower wage effects but higher rent effects - in that case, the directional plot points into the green, lower right quadrant. Increasing wage effects with falling rent effects are interpreted as a shift towards consumption disamenities (the upper left, purple quadrant). Equally, the length of the move also has a clear interpretation in encapsulating the size of the change. Since we are mostly interested in the direction of change, we standardize the vectors so the initial pair of coordinates is set to (0, 0) and the destination coordinate is accordingly rescaled. With the rescaling, the directional plots have no interpretation in the level of wage and rent effects - the level is represented in the preceding and ensuing map. The directions and size can be compared across different decades, however; and the directional lines represent the change for each individual city shown on the maps. It is possible to see that, although the exact direction for each city differs, the overall trend of the effect of manufacturing in the period 1970-80 was towards the upper right corner of the transition plot, implying that changes towards a production amenity.

As mentioned, our *storyboard* is essentially a sequence of snapshots that show the type of effect of a variable in a given year, concatenated by transitions that help understand how cities moved from one map to the next. Continuing the manufacturing example, Figure 2 contains its *storyboard*. It begins with the same plots as in Figure 1, and the following plots can be read exactly in the same way as the first scatter and transition graphs. Dot size and color intensity in the snapshots are set according to a global scale for the entire Figure, so that it is possible to make comparisons over time across maps of the same variable. Looking at the map for 1980, as anticipated by the first transition, the manufacturing sector has turned into a production amenity, acting thus as an attraction factor. This holds especially for the North East, but cities around the Great Lakes in 1980 also benefit from its effect.

The manufacturing sector strengthened its role as a force of attraction for firms up to the 1990s, where The North East, the Great Lakes, Florida and the East coast show strong attraction springing from the manufacturing industries. Our maps suggest this changed in 2000: almost all cities saw manufacturing associated with falling




NOTE: snapshots are color-coded using the following scheme: consumption amenity is green, consumption disamenity is purple, production amenity is blue and production disamenity is brown.

Figure 2: Manufacturing storyboard - 1970/2010

rents but larger wages, suggesting that it was hard to retain workers - large manufacturing industries have turned into disamenities to citizens. This is surprising given the large increases of manufacturing productivity growth over that decade, but could be explained by the accompanying low job growth (BLS, 2012), and changing consumption preferences for environment and services. The intensity of that effect, however, is not large. The last transition, from 2000 to 2010, shows that the negative role of manufacturing employment has changed to a production disamenity. Surprisingly, while manufacturing growth effects in the 1980s concentrated on the coasts, the negative effects associated with large manufacturing sectors play out strongly in the South (Louisiana, Texas).

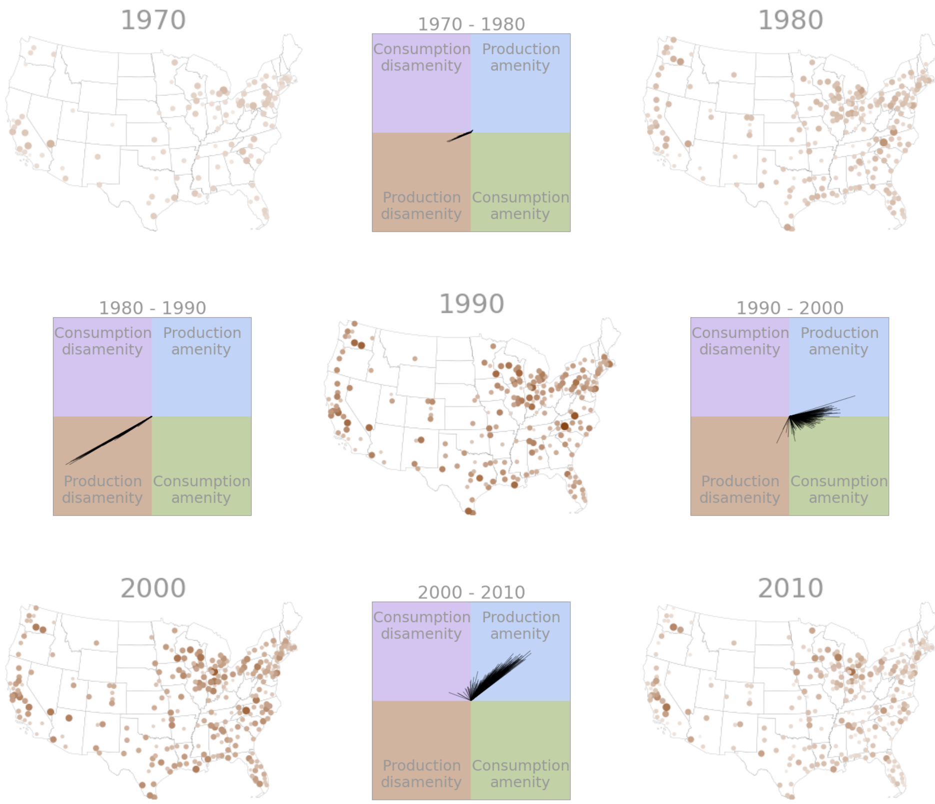
An alternative visualization that simply plots population changes requires fewer steps to interpret. However, the current approach offers alternative insights. Based on an underlying statistical model, it visualizes the attraction that an individual variable (manufacturing, college education) exerts rather than the variable itself - settting off our approach from more commonly used direct choropleths. It also helps understand how that variable contributed to city growth: whether it attracted firms followed by people, or vice versa. Furthermore, the Figure mixes maps of the level effects with transitional graphs, combining an understanding of the effects over space and over time.

## *Determinants of urban success, visually*

The *storyboard* technique can help convey the results of a complex economic model in a structured and intuitive way. As argued in the introduction, urban growth is also determined by many factors other than manufacturing. In this section, we apply the same approach to three other variables that have been highlighted by the economic literature as main determinants of urban growth: industrial specialization, college graduates (education), and share of employment in the service sector. The visual story we are able to tell follows the main conclusions the economics literature reaches but is also able to present them in a way that is more compelling and easy to understand.

High industrial specialization (Figure 3) has reduced wages as well as rents over all years in our sample. This suggests industrial specialization has predominantly repelled, rather than attracted firms. This is contrary to Marshallian theories of externalities, but in line with most empirical literature on industrial scale effects (Glaeser et al., 1992). The negative effects of specialization are mild in 1970, but grow worse over the years; in 1980 and especially 1990 some cities seem to strongly drive away firms based on their specialized industrial profiles. This effect seems particularly strong in the states of Washington and California, and around the Great Lakes. This patterns remains but grows less sharp in 2010. Interestingly, some commentators have speculated that strongly specialized cities are less resilient to crisis, but our results do not support that notion (in line with related literature, Brakman et al., 2014). The strongest effects play out in 2000 before the 2008 financial crisis, and in 2010, during a the crisis, the harmful effects of specialization have become milder, rather than worse.

The nature of education as a growth engine (figure 4) has not changed much, but its role has become a lot stronger over time. Ever since 1970, a large share of college educated citizens has functioned as a productive asset over time. This effect is already very strong in 1970 and grows in the subsequent decades. Interestingly, even in 1990, the high tide of manufacturing according to our results, the

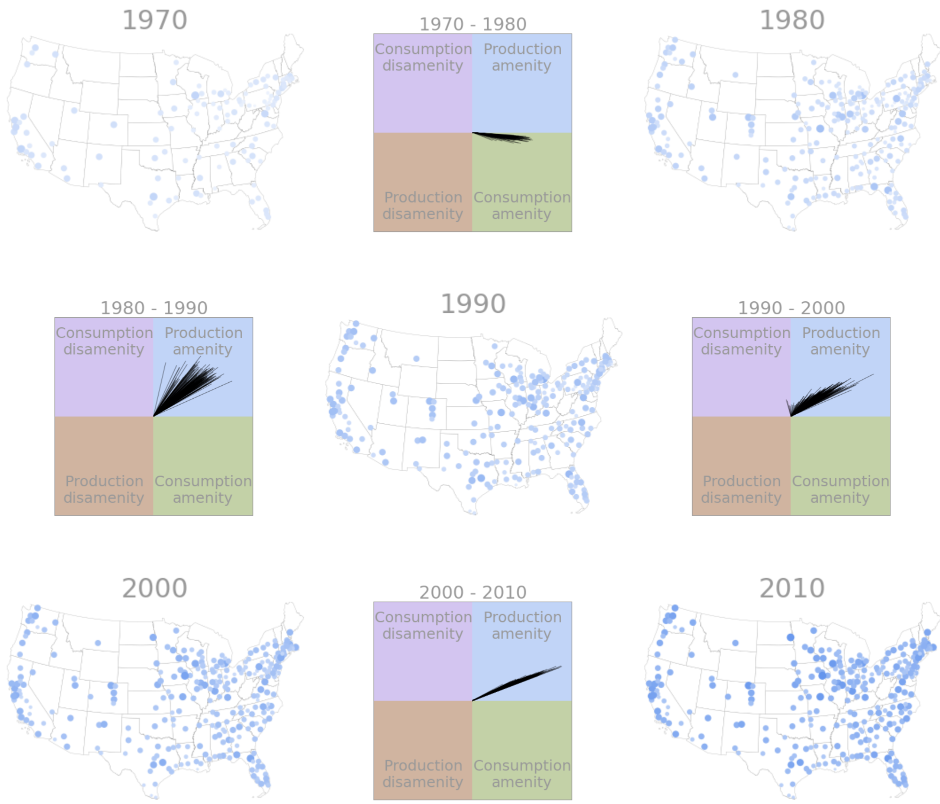



NOTE: snapshots are color-coded using the following scheme: consumption amenity is green, consumption disamenity is purple, production amenity is blue and production disamenity is brown.

Figure 3: Industrial specialization storyboard - 1970/2010

effects of education were stronger: increasing the shares of manufacturing employment and college degrees by one standard deviation yields similar wage effects, but the rent effect of college degrees was about three times as high (a 46 vs. 18 % points increase). The potential of an educated workforce is no secret to most policymakers (Glaeser and Saiz, 2003, were seminal for a large literature), but our results show these effects to be large in comparison. In contrast to our manufacturing employment results, there are no clear spatial delineations to the role of education - no area really stands out, and the transition dynamics shows fairly similar changes, suggesting the effects of educated populations grew alike in most cities. This contrasts intuition and some other results, suggesting that cities like Boston and the Northeast to have benefitted most from high education levels (Glaeser, 2005).

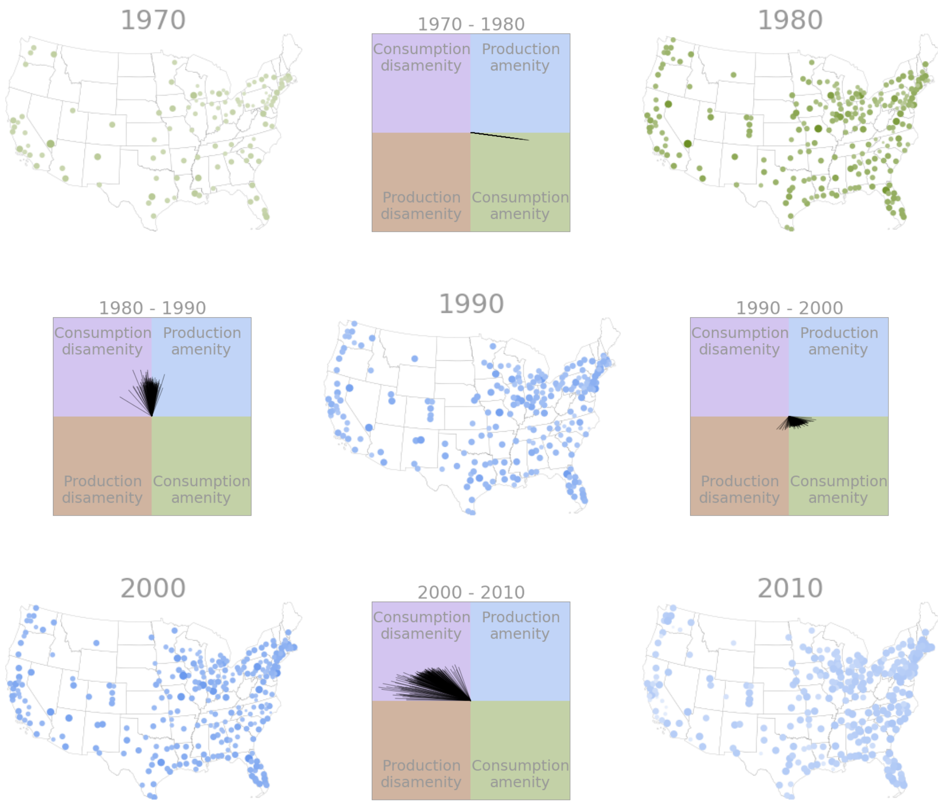
The forces of attraction from the service sector (Figure 5) show a clear change over time. In the 1970s, a larger service sector func-




NOTE: snapshots are color-coded using the following scheme: consumption amenity is green, consumption disamenity is purple, production amenity is blue and production disamenity is brown.

Figure 4: College storyboard - 1970/2010

tioned as a consumption amenity, attracting migrants rather than firms. This role is reinforced in the 1980s where, in all cities, the service sector moves into the direction of a consumption amenity even further. However, by 1990, services become an interest of firms, moving into the domain of production amenities (for some cities rent effects fall slightly; indicating a transition towards consumption disamenities, although the net effect remains a production amenity because the rent effects were large to start with). The change from green dots in 1980 to blue dots in 1990 indicates an unambiguous move to production amenities, and this pattern persists into 2000. In 2010, the patterns fades somewhat due to falling rents, although the net effect of services is still a production amenity at the end of our sample. Thus, interestingly, the service sector no longer predominantly serves as an amenity to migrating citizens, but attracts firms. Possibly, the growth of financial services is reflected in these data, which directly causes higher wages and rents, but also facilitates lo-




NOTE: snapshots are color-coded using the following scheme: consumption amenity is green, consumption disamenity is purple, production amenity is blue and production disamenity is brown.

Figure 5: Service storyboard - 1970/2010

cal credit (Greenwood and Scharfstein, 2013). Another possible explanation is that the service sector has changed nature from supplying final products to serving other businesses. This would coincide with increasingly fragmented production chains. However, this fragmentation seems to occur less within the US, suggesting that service-sector associated jobs could be on the rise due to imports and offshoring of other steps in the supply chain (Fally, 2011). The latter also coincides with the largest productive amenities located on the coasts.

## *Conclusion*

This paper visualizes the role of several engines of city growth in the US. After WWII, large manufacturing sectors formed a source of attraction for firms, especially by the coasts. More recently, however, the presence of large manufacturing employment seems to have lost its productive edges, particularly driving away firms in the

South. Industrial specialization seems to have played a negative role during the entire period analyzed and throughout the geography, mainly deterring firms from locating there. The presence of a large service sector was considered a consumption amenity in the 1970s and 1980s, but switched to productive asset in the decades after, attracting firms rather than people. Lastly, the role of eduction has grown over the last half century. While to some, an educated population may be a motive to migrate to a city, our results show that educated workforces primarily attract firms. Not only is the effect of a college-educated workforce growing over time, it is increasingly a productive asset to the city. Engines of growth change over time, but also over space: manufacturing changes from productive asset to consumers' liability, with place-specific impacts, while higher education has productive growth effects that are relatively uniform across the country.

Our visualization approach has two distinct merits, in our view. Firstly, it is able to uncover more complicated patterns in urban change. It can make clear not only that manufacturing or education was an important engine of growth, but also where and in what years its impact was large, as well as whether it improved quality of life or job prospects. This contributes to overcome the "one size fits all" mantra, common in many policies, highlighting conditions or circumstances in which cities could attempt to get higher educated individuals, attract specific industries, or exploit their amenities. Secondly, in many ways, the representation of the results is more accessible - the *storyboard* conveys a scenario rather than numbers. Moving beyond equations and raw regression output enables policy makers, journalists and other non-technical audiences to better interpret and engage with these models of urban change at a more complete level. This has a democratization effect in that it rebalances the status quo where audiences without significant mathematical background traditionally had little access to these sorts of results. The storyboard methodology is an example of an attempt to not only help understanding and interpreting scientific results through visualization, but also of how to multiply the research impact by communicating it to a wider audience.

While we argue that our approach allows for a more disaggregated analysis, there are some drawbacks and limitations, too. Firstly, the approach is exploratory rather than explanatory - it may give new insights but we have not provided a statistical test of, e.g., the differences between cities. Therefore we believe our results can provide ideas for policy design, but not substantiate it statistically. In addition, as presented here, the approach is not interactive. One could argue that, given its focus on exploration and discovery, an environment in which the user could interact with the visualization by zooming in, querying names of cities or estimate values, would be more powerful. Such an approach could even be further enhanced by introducing fully linked views: a system where the user could, for example, select a city in one of the snapshots and its corresponding line segment in the transition view and the rest of the *storyboard* was highlighted as well. Secondly, while the disaggregation is more detailed than a single regression analysis coefficient, it is impossible to avoid aggregation in some dimension. In our analysis, we have chosen to allow the effect of growth engines to be constant over all cities in one year - a 10 percentage point increase share of manufacturing in total employment raises rents and wages by the same percentage, whether the city is large or small, or manufacturing intense or not. While arguably manufacturing follows a comparable technology for all cities same year, we ignore differences in, for instance, the type of manufacturing or whether cities have ports to ship. Thirdly, the visualization relies on an underlying economic model, which is inevitably a simplification of reality. There are, of course, instances where wage and rent changes (or their absence) are not determined by market forces. In such cases, our results would be biased (Albouy, 2008). When prices and wages are regulated, it is also hard or impossible to apply our methodology. A last, fair objection we want to mention is that we have focused on the visualization, not paying particular attention to causality. Cities might have features that both attract manufacturing firms and increase land rents, invalidating a causal interpretation. We fully acknowledge this issue, but argue that it is potentially solvable by taking the identification problem into account in the underlying regression, a modification that would not change the role of visualization in exploiting its results.

## *References*

Albouy, D. (2008). Are Big Cities Bad Places to Live? Estimating Quality of Life across Metropolitan Areas. NBER Working Papers 14472, National Bureau of Economic Research, Inc.

Autor, D. H. and Dorn, D. (2013). The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market. *American Economic Review*, 103(5):1553–97.

Batty, M. (2012). Smart cities, big data. *Environment and Planning B: Planning and Design*, 39(2):191–193.

Batty, M. and Cheshire, J. (2012). Visualisation tools for understanding big data. *Environment and Planning B: Planning and Design*, 39(3):413–415.

Blinder, A. S. (1996). Offshoring: the next industrial revolution? *Foreign Affairs*, 85(2):113–128.

BLS (2012). International comparisons of GDP per capita and per hour, 1960-2011. Technical report, Bureau of Labor Statistics: Division of International Labor Comparisons.

Brakman, S., Garretsen, H., and van Marrewijk, C. (2014). The Crisis and Regional Resilience in Europe: On the Importance of Urbanization and Specialization. CESifo Working Paper Series 4724, CESifo Group Munich.

Combes, P.-P., Duranton, G., Gobillon, L., Puga, D., and Roux, S. (2012). The Productivity Advantages of Large Cities: Distinguishing Agglomeration From Firm Selection. *Econometrica*, 80(6):2543–2594.

Fally, T. (2011). On the fragmentation of production in the us. *University of Colorado mimeo*.

Florida, R. (2002). *The Rise of the Creative Class: And How itŠs transforming work, leisure, community and everyday life*. Perseus Book Group, New York.

Flynn, N. and Taylor, A. P. (1986). Inside the rust belt: an analysis of the decline of the West Midlands economy. 1: International and national economic conditions. *Environment and Planning A*, 18(7):865–900.

Glaeser, E. L. (2005). Reinventing Boston: 1630–2003. *Journal of Economic Geography*, 5(2):119–153.

Glaeser, E. L., Kallal, H. D., Scheinkman, J. A., and Shleifer, A. (1992). Growth in Cities. *Journal of Political Economy*, 100(6):1126–52.

Glaeser, E. L., Kolko, J., and Saiz, A. (2001). Consumer city. *Journal of Economic Geography*, 1(1):27–50.

Glaeser, E. L. and Saiz, A. (2003). The Rise of the Skilled City. NBER Working Papers 10191, National Bureau of Economic Research, Inc.

Greenwood, R. and Scharfstein, D. (2013). The growth of finance. *Journal of Economic Perspectives*, 27(2):3–28.

Henderson, J. V. and Wang, H. G. (2007). Urbanization and city growth: The role of institutions. *Regional Science and Urban Economics*, 37(3):283 – 313.

Klein, A. and Crafts, N. (2012). Making sense of the manufacturing belt: determinants of U.S. industrial location, 1880–1920. *Journal of Economic Geography*, 12(4):775–807.

Krugman, P. (1991). History and Industry Location: The Case of the Manufacturing Belt. *American Economic Review*, 81(2):80–83.

Ottaviano, G. I. and Peri, G. (2006). The economic value of cultural diversity: evidence from US cities. *Journal of Economic Geography*, 6(1):9–44.

Rappaport, J. (2003). U.S. urban decline and growth, 1950 to 2000. *Economic Review*, (Q III):15–44.

Roback, J. (1982). Wages, Rents, and the Quality of Life. *Journal of Political Economy*, 90(6):1257–78.

Shapiro, J. M. (2006). Smart cities: quality of life, productivity, and the growth effects of human capital. *The review of economics and statistics*, 88(2):324–335.

Storper, M. and Scott, A. J. (2009). Rethinking human capital, creativity and urban growth. *Journal of Economic Geography*, 9(2):147–167.

Tufte, E. (1983). *The visual display of quantitative information*. Graphics press.

## *References*

Albouy, D. (2008). Are Big Cities Bad Places to Live? Estimating Quality of Life across Metropolitan Areas. NBER Working Papers 14472, National Bureau of Economic Research, Inc.

Autor, D. H. and Dorn, D. (2013). The Growth of Low-Skill Service Jobs and the Polarization of the US Labor Market. *American Economic Review*, 103(5):1553–97.

Batty, M. (2012). Smart cities, big data. *Environment and Planning B: Planning and Design*, 39(2):191–193.

Batty, M. and Cheshire, J. (2012). Visualisation tools for understanding big data. *Environment and Planning B: Planning and Design*, 39(3):413–415.

Blinder, A. S. (1996). Offshoring: the next industrial revolution? *Foreign Affairs*, 85(2):113–128.

BLS (2012). International comparisons of GDP per capita and per hour, 1960-2011. Technical report, Bureau of Labor Statistics: Division of International Labor Comparisons.

Brakman, S., Garretsen, H., and van Marrewijk, C. (2014). The Crisis and Regional Resilience in Europe: On the Importance of Urbanization and Specialization. CESifo Working Paper Series 4724, CESifo Group Munich.

Combes, P.-P., Duranton, G., Gobillon, L., Puga, D., and Roux, S. (2012). The Productivity Advantages of Large Cities: Distinguishing Agglomeration From Firm Selection. *Econometrica*, 80(6):2543–2594.

Fally, T. (2011). On the fragmentation of production in the us. *University of Colorado mimeo*.

Florida, R. (2002). *The Rise of the Creative Class: And How itŠs transforming work, leisure, community and everyday life*. Perseus Book Group, New York.

Flynn, N. and Taylor, A. P. (1986). Inside the rust belt: an analysis of the decline of the West Midlands economy. 1: International and national economic conditions. *Environment and Planning A*, 18(7):865–900.

Glaeser, E. L. (2005). Reinventing Boston: 1630–2003. *Journal of Economic Geography*, 5(2):119–153.

Glaeser, E. L., Kallal, H. D., Scheinkman, J. A., and Shleifer, A. (1992). Growth in Cities. *Journal of Political Economy*, 100(6):1126–52.

Glaeser, E. L., Kolko, J., and Saiz, A. (2001). Consumer city. *Journal of Economic Geography*, 1(1):27–50.

Glaeser, E. L. and Saiz, A. (2003). The Rise of the Skilled City. NBER Working Papers 10191, National Bureau of Economic Research, Inc.

Greenwood, R. and Scharfstein, D. (2013). The growth of finance. *Journal of Economic Perspectives*, 27(2):3–28.

Henderson, J. V. and Wang, H. G. (2007). Urbanization and city growth: The role of institutions. *Regional Science and Urban Economics*, 37(3):283 – 313.

Klein, A. and Crafts, N. (2012). Making sense of the manufacturing belt: determinants of U.S. industrial location, 1880–1920. *Journal of Economic Geography*, 12(4):775–807.

Krugman, P. (1991). History and Industry Location: The Case of the Manufacturing Belt. *American Economic Review*, 81(2):80–83.

Ottaviano, G. I. and Peri, G. (2006). The economic value of cultural diversity: evidence from US cities. *Journal of Economic Geography*, 6(1):9–44.

Rappaport, J. (2003). U.S. urban decline and growth, 1950 to 2000. *Economic Review*, (Q III):15–44.

Roback, J. (1982). Wages, Rents, and the Quality of Life. *Journal of Political Economy*, 90(6):1257–78.

Shapiro, J. M. (2006). Smart cities: quality of life, productivity, and the growth effects of human capital. *The review of economics and statistics*, 88(2):324–335.

Storper, M. and Scott, A. J. (2009). Rethinking human capital, creativity and urban growth. *Journal of Economic Geography*, 9(2):147–167.

Tufte, E. (1983). *The visual display of quantitative information*. Graphics press.