The Decline of the U.S. Rust Belt: A Macroeconomic Analysis

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Abstract

While the United States as a whole saw robust increases in economic activity over the post-war period, the economic performance of regions within the country was highly unequal. In this paper we document that the regions that fared relatively worst in terms of wage and employment growth were those that paid workers the largest wage premiums in 1950. We use this evidence to develop a theory of the decline of the "Rust Belt," the highly-unionized manufacturing zone around the Great Lakes. Our theory is that limited competition in labor markets and output markets in the Rust Belt was responsible for much of the region's decline. We formalize the theory in a dynamic general equilibrium model in which productivity growth and regional employment shares are determined by the extent of competition. Evidence from prominent Rust Belt industries supports the model's prediction that investment and productivity growth rates were relatively low in the Rust Belt.

Keywords: Rust Belt, competition, productivity, unionization, monopoly

JEL codes: E24, E65, J3, J5, L16, R13

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1. Introduction

While the United States as a whole saw robust increases in economic activity over the postwar period, the economic performance of regions within the country was highly unequal. The region that arguably fared worst of all is the portion of the Midwest and Northeast known as the "Rust Belt." While there is no standard definition of the Rust Belt, it has generally come to mean the heavy manufacturing zone near the Great Lakes that includes cities such as Detroit, Cleveland and Pittsburgh.[1] The salient characteristic of the region is that, by any definition, its employment and wage growth has lagged far behind the rest of the country since the end of World War II.

In this paper we document a new set of facts about the relative performance of U.S. regions, and the Rust Belt in particular, over the postwar period. We document that the Metropolitan Statistical Areas (MSAs) with the lowest relative wage and employment growth from 1950 to 2000 tended to be those in which workers were paid the highest wage premiums in 1950. Furthermore, most of the MSAs with the highest wage premiums in 1950 and worst subsequent economic performance are located in the Rust Belt. We define a region's wage premium as its average hourly wage relative to what one would expect given its workers' level of schooling and experience.

We then use these facts to motivate a theory of the decline of the Rust Belt. In short, our theory is that the Rust Belt declined due to a lack of competition in labor markets and output markets in its most important industries. The prime examples are steel, automobile and rubber manufacturing. The lack of competition in labor markets was closely linked to the behavior of the powerful labor unions that dominated each of the major Rust Belt industries for much of the postwar period. In output markets, the major Rust Belt industries were each run by a small set of oligopolists who, according to numerous sources, actively discouraged competition for decades after the end of WWII. We argue that this lack of competition served to depress investment and productivity growth, which led to a movement of economic activity out of the Rust Belt and into other parts of the country (notably the "Sun Belt" in the U.S. South.)

We formalize the theory in a dynamic general equilibrium model in which the extent of competition determines productivity growth. There is a continuum of goods in the economy, with some fraction produced in the "Rust Belt" and the rest produced in the "Sun Belt." The two regions differ only in the extent of competition they face. Rust Belt producers must hire workers through competitive bargaining with a labor union, which demands the competitive wage per each worker plus some fraction of the surplus from production. Sun Belt producers pay only the competitive wage. In output markets, both regions face a competitive fringe with whom they engage in Bertrand competition. We assume that Rust Belt producers can (exogenously) block the fringe to some extent,

[1] Our definition of the Rust Belt is Illinois, Indiana, Michigan, New York, Ohio, Pennsylvania and Wisconsin.

while Sun Belt producers cannot. Firms in both regions have the ability to undertake investment which, at a cost, increases the productivity of any workers hired.

The main prediction of the theory is that the lesser the extent of competition in either labor or output markets in the Rust Belt, the lower its investment and productivity. We first illustrate this result qualitatively in a simple static version of the theory. We show there are two effects which drive the theory's prediction. The first effect is a "hold up problem" which arises through the collective bargaining process. Since Rust Belt firms alone occur investment costs, but firms and workers share the surplus generated by the investment, Rust Belt producers optimally choose to invest less ex-ante than they otherwise would. The second effect comes from differences in output market competition. The inability of Sun Belt producers to block the competitive fringe gives producers there a stronger incentive to invest in order to "escape the competition" (as in the work of Acemoglu and Akcigit (2011) and Aghion, Bloom, Blundell, Griffith, and Howitt (2005), among others.) This incentive is less prevalent among Rust Belt producers, and hence they invest less.

We then embed this simple static framework in a richer dynamic model in which the productivity and employment shares in each region evolve endogenously over time. Because goods are gross substitutes, employment and output tend to move to the region that has the highest productivity growth, as in the model of Ngai and Pissarides (2007). We discipline the extent of competition in the model using our measures of wage premiums and estimates of the markups in key Rust Belt industries from 1950 to 2000. We then compute the model's predictions for the share of total employment in the Rust Belt and compare it to the data. We find that the model predicts roughly *one half* the decline found in the data.

We conclude by presenting several types of evidence supporting the theory's prediction that investment and productivity growth rates were relatively low in the Rust Belt. First, we show that direct measures of TFP growth in prominent Rust Belt industries were lower than those of the rest of the economy. Second, we present estimates of technology adoption rates by country showing that the Rust Belt producers tended to lag behind their counterparts in Europe and Asia for much of the postwar period. Finally, we cite historical studies of Rust Belt industries which argue directly that investment and productivity growth were far lower than they could have been.

Our paper relates closely to a recent and growing literature linking competition and productivity. As Holmes and Schmitz (2010), Syverson (2011) and Schmitz (2012) argue, there is now a substantial body of evidence linking greater competition to higher productivity. As one prominent example, Schmitz (2005) shows that in the U.S. Iron Ore industry there were dramatic improvements in productivity following an increase in competitive pressure in the early 1980s, largely due to efficiency gains made by incumbent producers. Similarly, Bloom, Draca, and Reenan (2011) provide evidence that European firms most exposed to trade from China in recent years were those

that innovated more and saw larger increases in productivity. Pavcnik (2002) documents that after the 1980s trade liberalization in Chile, the producers facing new import competition saw the largest gains in productivity, in part because of efficiency improvements by existing producers. A common theme with these papers and ours is that competition reduced rents to firms and workers and forced them to improve productivity. Along these lines, our work also relates closely to that of Cole and Ohanian (2004), who argue that policies that encouraged non-competitive behavior in the industrial sector during the Great Depression depressed aggregate economic activity even further.

From a modeling perspective, our work builds on several recent studies in which model firms innovate in order to "escape the competition," such as in the work of Acemoglu and Akcigit (2011) and Aghion, Bloom, Blundell, Griffith, and Howitt (2005). The common theme is that greater competition in output markets encourages incumbent firms to innovate more in order to maintain a productivity advantage over potential entrants. Our model also relates to those of Parente and Prescott (1999) and Herrendorf and Teixeira (2011), in which monopoly rights reduce productivity by encouraging incumbent producers from blocking new productivity-enhancing technologies.

Our paper also complements the literature on the macroeconomic consequences of unionization. The paper most related to ours in this literature is that of Holmes (1998), who uses geographic evidence along state borders to show that state policies favoring labor unions greatly depressed manufacturing productivity over the postwar period. Our work also resembles that of Taschereau-Dumouchel (2012), who argues that even the threat of unionization can cause non-unionized firms to distort their decisions so as to prevent unions from forming, and that of Bridgman (2011) who argues that a union may rationally prefer inefficient production methods so long as competition is sufficiently weak.[2]

To the best of our knowledge we are the first to explore the role of competition in understanding the Rust Belt's decline. Our work contrasts with that of Yoon (2012), who argues that the Rust Belt's decline was due (in part) to rapid technological change in manufacturing, and Glaeser and Ponzetto (2007), who argue that the declines in transportation costs eroded the Rust Belt's natural advantage in shipping goods via waterways. Our paper also differs from the work of Blanchard and Katz (1992) and Feyrer, Sacerdote, and Stern (2007), who study the long-term consequences of the Rust Belt's decline in employment (rather than the root causes of the decline.) Our model

[2]While our model takes the extent of competition in labor markets (unionization) as exogenous, several recent studies have modeled the determinants of unionization in the United States over the last century. Dinlersoz and Greenwood (2012) argue that the rise of unions can be explained by technological change biased toward the unskilled, which increased the benefits of their forming a union, while the later fall of unions can be explained by technological change biased toward machines. Relatedly, Acikgoz and Kaymak (2012) argue that the fall of unionization was due instead to the rising skill premium, caused (perhaps) by skill-biased technological change. A common theme in these papers, as in the work of Taschereau-Dumouchel (2012), is the link between inequality and unionization, and the union's role in reducing inequality, which is absent from the current paper.

is consistent with their finding that employment losses sustained by Rust Belt industries led to population outflows rather than persistent increases in unemployment rates.

2. Empirical Findings

In this section we describe our empirical finding that regions with the worst relative performance in wage and employment growth from 1950 to 2000 were those that the highest wage premiums in 1950.

2.1. Census Micro Data

We begin with the description of the data used for our calculations. Our basic data are the decadal United States Censuses of 1950 through 2000 available through the Integrated Public Use Microdata Series (IPUMS). For each census we draw on either a 1% or 5% sample of individuals (depending on availability) of the entire U.S. population. The data allow us to compute, among other things, the age and education level of every individual in the sample, plus labor earnings and hours worked for all employed individuals. We also know the industry of employment for all workers, and whether or not they are self-employed.

Crucially, the data also report where each individual lives. The unit of geography which we employ throughout the paper is the Metropolitan Statistical Area (MSA), which corresponds roughly to a city plus its surrounding suburbs. We report MSA-level statistics for all MSAs in the country that are above a certain size threshold, usually around 100,000 people. The place of residence is excluded for confidentiality reasons in smaller MSAs or rural areas. We also focus attention to 3-digit MSAs as defined by IPUMS, as these have changed definition relatively infrequently over time (unlike the 4-digit MSAs.)

In our main analysis we restrict the sample of individuals as follows. First, we take only workers who report being primarily wage earners, as opposed to the self-employed. Second, we take only private sector workers. Third, we take only males that worked at least 1,500 hours in the previous year. The reason for these restrictions are to limit possible biases in our measurement of wage premiums, as well as to keep our sample as standard as possible. We note that our results carry over to alternative sample restrictions, and discuss some of these in detail below.

2.2. Decline of the Rust Belt

Our baseline definition of the Rust Belt throughout the paper is the region encompassing Illinois, Indiana, Michigan, New York, Ohio, Pennsylvania and Wisconsin. Figure 1 plots the Rust Belt's share of total employment (solid black line) and share of manufacturing employment (dashed red

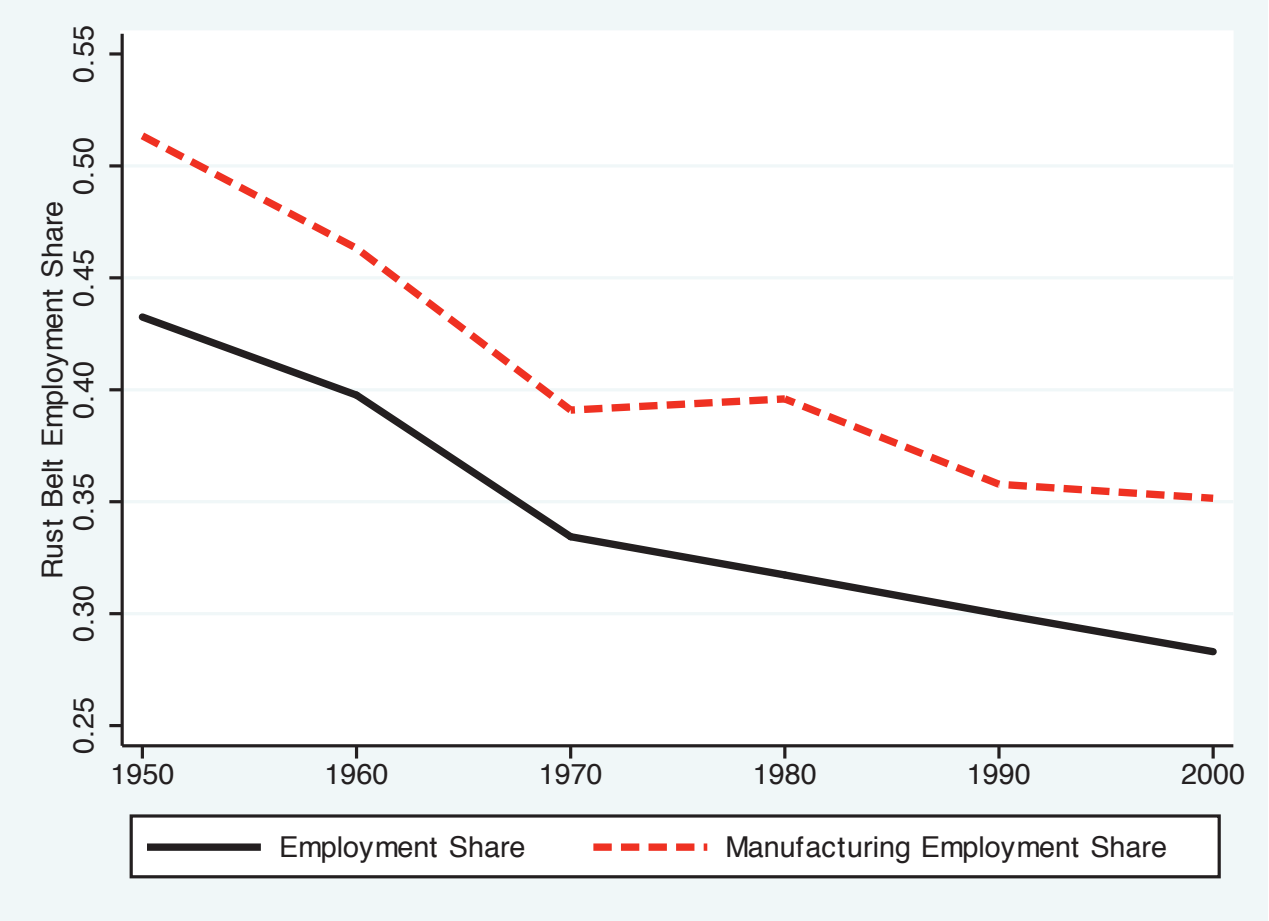


Figure 1: The Rust Belt's Employment Share and Manufacturing Employment Share

line). The solid line shows that the Rust Belt's share of aggregate economic activity fell dramatically. In 1950, the Rust Belt employed about 44% of all workers in the United States, and by 2000 this share had fallen to around 28%.

Figure 1 also suggests that the decline of the Rust Belt is not a simple story about structural change. That is, the Rust Belt's decline was not simply because the U.S.'s manufacturing sector declined, and the Rust Belt happened to be manufacturing intensive. The dashed red line in Figure 1 shows that the Rust Belt's share of employment declined *even within the manufacturing sector*. In 1950, just over half of manufacturing employment was located in the Rust Belt, but by 2000 this share was down to just over one third. Figure A.1, in the Appendix, shows that in absolute levels, manufacturing employment in the Rust Belt declined slightly over this period (by around 10%.) In contrast, manufacturing employment in the United States excluding the Rust Belt increased dramatically, by over 80% from 1950 to 2000. What was happening, these figures suggest, is that manufacturing employment was moving from the Rust Belt to elsewhere in the country.

2.3. Measure of Wage Premiums

We construct our measures of wage premiums as follows. As in many standard macroeconomic models, we assume that under competition, the workers' wage should be proportional to their human capital. Following the tradition of Mincer, we assume that a worker's human capital is a function their schooling and potential work experience. We build on these assumptions by letting a worker's wage depend on where they live, with some regions offering a larger payment per unit of human capital than others. In particular, we assume that the log hourly wage of worker i in region m is

$$\log w_{i,m} = \alpha \cdot SCHOOL_{i,m} + \sum_{j=1}^{4} \beta_j \cdot EXPER_{i,m}^{j} + \sum_{m=1}^{M} D_m \cdot \pi_m + \varepsilon_{i,m} \tag{1}$$

where $SCHOOL_{i,m}$ and $EXPER_{i,m}$ represent years of schooling and potential experience, D_m is a dummy for residing in region m, and $\varepsilon_{i,m}$ is an error term. The coefficients α and β_1 through β_4 capture the returns to schooling and experience while the π_m terms capture the "premium" that a worker earns for living in region m controlling for schooling and experience.

We estimate (1) using the IPUMS micro data (from 1950), and take the π_m terms as our measure of wage premiums by MSA. We emphasize that these measures are best thought of as suggestive due to the crude way in which they are calculated. One limitation for example is that other potentially important MSA-level characteristics are omitted from the regression, such as cost-of-living indices. Another limitation is that schooling and potential experience themselves are imperfect proxies for human capital. Nevertheless, we argue that these wage premium measures are still useful in describing and understanding regional differences in economic performance over the post-war period.

2.4. Wage Premiums and Growth in Employment and Wages

We now document our main empirical finding, which is that cities that experienced the lowest employment and wage growth from 1950 to 2000 tended to have the highest wage premiums in 1950. Figure 2 shows the wage premium in 1950 (normalized to 0) plotted against the annualized growth in employment from 1950 to 2000. Rust Belt MSAs are displayed in red, while the rest are black. As can be seen in the figure, there is a negative correlation between the two variables, with regions with the highest premiums in 1950 tending to have the worst subsequent employment growth. The correlation coefficient is -0.44, and is significant at well below the 1% level.

Figure 3 shows the wage premium plotted against annualized wage growth from 1950 to 2000. Rust Belt MSAs are again displayed in red. The relationship is negative here too, and even stronger than the one between the premiums and employment growth. The correlation coefficient is -0.60

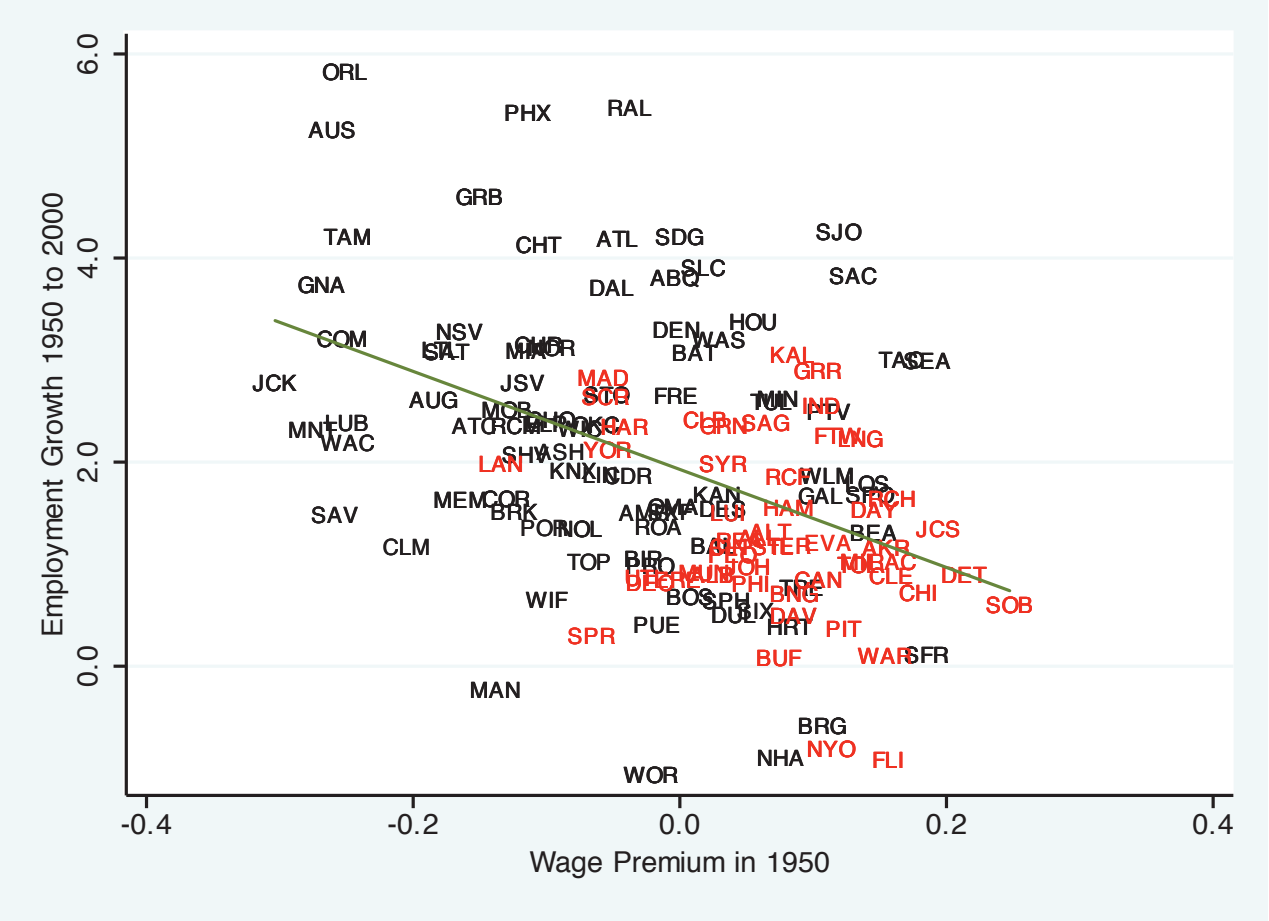


Figure 2: Wage Premiums and Employment Growth across MSAs

and significant at well below the 1% level. Table A.1 (in the Appendix) shows that the negative relationships between the wage premiums and both wage growth and employment growth are robust when looking at full-time workers of both sexes or all workers of both sexes. In addition, we find that the relationship holds when looking at growth in average household income or median household income.

Which are the regions on either end of the spectrum? Among the MSAs with high wage premiums are South Bend, IN (SOB), Detroit, MI (DET), Jackson, MI (JCS), Chicago-Gary-Lake, IL (CHI), Pittsburgh, PA (PIT), Youngstown-Warren, OH (WAR), and Flint, MI (FLI). Each of these MSAs was home in 1950 to a major manufacturing center in the automobile or steel industries.[3] Among those with low wage premiums are Orlando, FL (ORL), Austin, TX (AUS), Phoenix, AZ (PHX), Raleigh-Durham, NC (RAL) and Greensboro-Winston Salem-High Point, NC (GRB).

[3]See e.g. Vlasic (2011) or Ingrassia (2011) on auto manufacturing, and Tiffany (1988) or Crandall (1981) on steel. South Bend, Detroit, Jackson and Flint were major auto producers; Pittsburgh, Youngstown-Warren and Chicago-Gary-Lake were steelmaking centers.

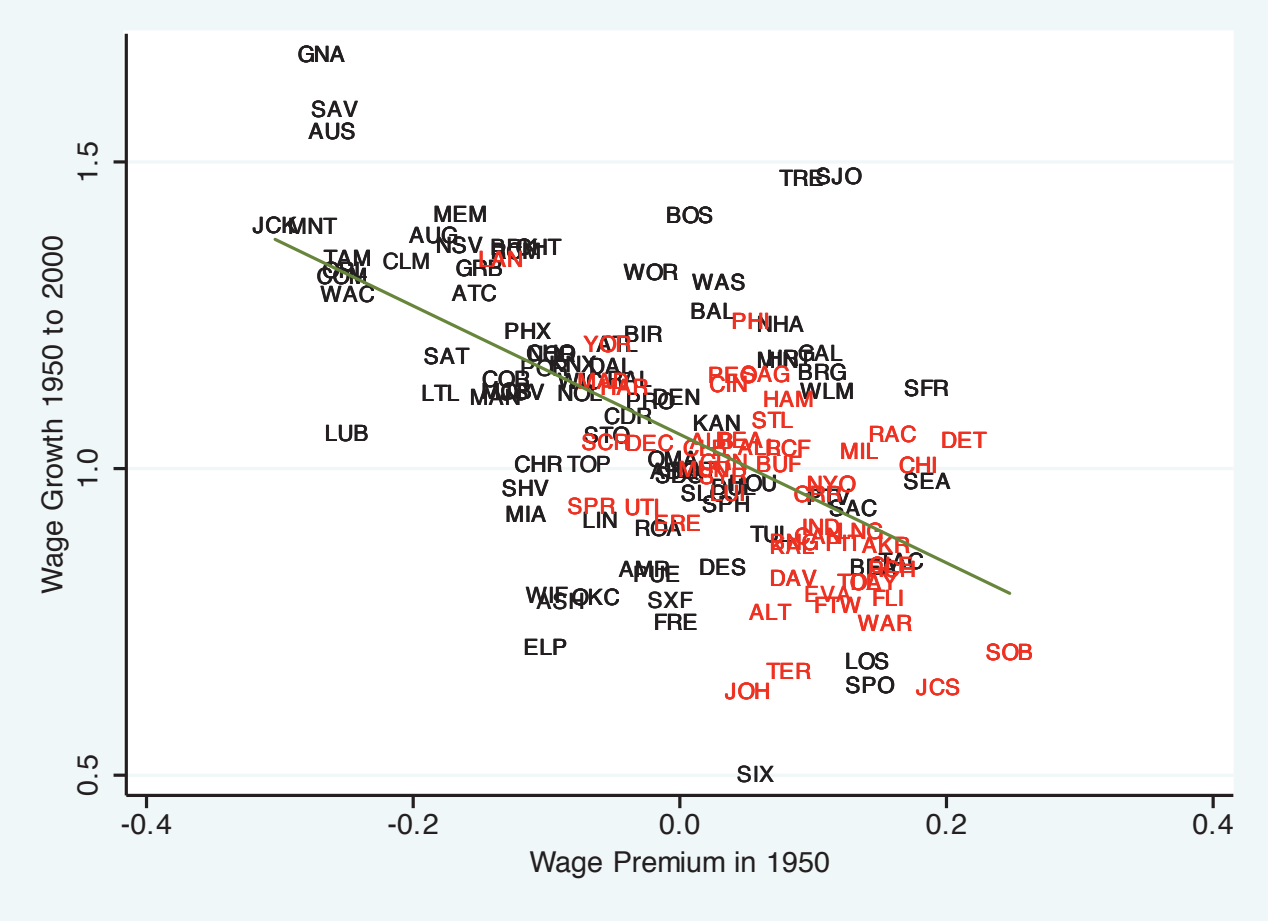


Figure 3: Wage Premiums and Wage Growth across MSAs

These MSAs have all been referred to as being part of the "Sun Belt" (by Blanchard and Katz (1992), among others).

3. Lack of Competition in the Rust Belt

In this section we argue that a very likely interpretation of the large wage premiums found in the Rust Belt region is a lack of competition in labor markets. We then argue that the lack of competition in the Rust Belt was more general, and likely pertained to output markets as well.

3.1. Lack of Competition in Labor Markets

Thus far we have not provided any economic interpretation for the observed wage premiums. A high wage premium could in principle reflect that the regions' workers are simply positively selected on unobserved characteristics that are valuable in production. Instead, we ask whether the premiums reflect a non-competitive labor market, at least for those cities with the highest wage

premiums. The interpretation we consider is that non-competitive labor markets lead workers to earn wages in excess of their marginal products.

The prime piece of information supporting the view that the measured wage premiums reflect rents earned by the workers is that most of the MSAs with high wage premiums were highly unionized (Goldfield, 1987). The United States as a whole was highly unionized right after WWII, and the best available disaggregated evidence (from the state-level unionization database of **?**) suggests that the Rust Belt was much more unionized than the rest of the country (see Figure A.2.)

Two industries, steel and automobiles, and two unions, the United Steelworkers (USW) and United Auto Workers (UAW), dominated the majority of these cities. The highest concentration of auto workers were Flint and Detroit, with 52% and 29% of all workers in these regions employed in automobile manufacturing. South Bend, Toledo, OH (TOL) and Racine, WI (RAC) were also major automobile producing regions. As for steel, 27% and 17% of all workers in Youngstown-Warren and Pittsburgh were steel workers, respectively, making these two cities two of the most steel intensive regions in the country in 1950. The Chicago-Gary-Lake MSA was also a major steel center, with most of the steel mills located in Gary.[4]

There is ample direct evidence that unions such as the United Steelworkers and United Auto Workers were able to extract large wage premiums for their workers. Ingrassia (2011) and Vlasic (2011) document that the UAW extracted larger and larger wages, benefits and other controls over production from the "Big Three" of Ford, General Motors and Chrysler from WWII through the 1970s. By 1973, a UAW worker could earn "princely sums" working on production or other union-created jobs, such as serving on the plant recreation committee, and then retire with full benefits as early as age 48 (Ingrassia, 2011, pp. 46, 56). Tiffany (1988) states that in 1959, average hourly earnings for steel workers were more than 40% higher than the all-manufacturing average in the United States (p. 178).[5]

One potential alternative theory of the wage premiums in the Rust Belt is that workers there were of higher than average ability. This could be the case, say, if talented workers in the 1950s tended to be attracted disproportionately to the Rust Belt regions because labor markets there were strong at the time. According to this theory, the interpretation of the above-average wages as premiums

[4]Other MSAs with high wage premiums were not involved primarily in steel or autos, but in other types of manufacturing. For example, Akron, OH (AKR) was once known as the "Rubber Capital of the World," with all four major U.S. rubber manufacturers at the time located there (e.g. Goodyear, Firestone, U.S. Rubber and Goodrich.) Virtually all rubber workers were organized into the United Rubber Workers union (French, 1991), which later became part of the USW. As another example, Terre Haute, IN (TER) was a diverse manufacturing center in 1950, with substantial employment in industries such as steel and meat packing, and a powerful union presence, including from the United Auto Workers (Goldfield, 1987).

[5]More generally, there is a long literature documenting sizable union wage premiums in the United States (Blanchflower and Bryson, 2004).

is erroneous, and instead the higher than average wages earned by workers in this region simply reflected their higher productivity.

One piece of evidence against this hypothesis is that workers in industries common in the Rust Belt tended to suffer some of the largest wage losses in percent terms after a (plausibly) exogenous displacement, compared to workers in other industries (Carrington and Zaman, 1994; Jacobson, Lalonde, and Sullivan, 1993). Carrington and Zaman (1994) find that displaced workers in the typical industry lost about 10% of their pre-displacement wage when moving to a new job. In contrast, workers in the "primary metal manufacturing" industry lost around 26% of their wages, and workers in "transport equipment manufacturing" and "rubber and plastics manufacturing" lost around 20%. This evidence is more consistent with the hypothesis that these workers were earning wage premiums than with the hypothesis that these workers were disproportionately the most productive workers.

3.2. Lack of Competition in Output Markets

In many major industries in the Rust Belt, production was dominated by just a few firms for most of the postwar period. The largest three steel producers – U.S. Steel, Bethlehem Steel, and National Steel – had at least half the U.S.'s total steel capacity from the end of WWII through 1980 (Crandall, 1981; Tiffany, 1988). The three largest car industries – Ford, General Motors and Chrysler – accounted for 90% of automobile sales in the United States in 1958, and the majority of the domestic market for several decades afterwards (Ingrassia, 2011, p. 28). A similar dominance pertained to the four largest rubber tire producers, who had at least 90% of the market in every year from 1950 to 1970 (French, 1991).

Furthermore, there is evidence that the few producers in each of the important Rust Belt industries behaved non-competitively. Adams and Brock (1995, p. 94) describe the big Steel producers as having had "virtually unchallenged control of a continent-size market," which led to a "well-honed system of price leadership and follower-ship" (with U.S. Steel as the leader). Similarly, Ingrassia (2011, p. 29) describes the automobile industry as being a "model of corporate oligopoly" throughout the 1950s, 1960s and 1970s, with General Motors playing the role of the price leader.[6]

Both steel and autos, as well as rubber, were accused on multiple occasions of explicit collusion. In 1959, the Federal Trade Commission (FTC) charged fifteen rubber manufacturers with agreeing on common list prices and discounting policy (French, 1991).[7] Tiffany (1988) describes several

[6] Adams and Brock (1995, p. 78) write that "the prices adopted by the Big Three [auto manufacturers] appear at times to represent the outcome of a tacit bargain arrived at through a delicate process of communication and signaling.... Once they have revealed their hands to one another, then they announce their final prices, which, not surprisingly, tend to be quite similar."

[7] The FTC claimed that the rubber manufacturers had revived the cooperative policies granted to them in the 1930s

similar instances in Steel, and on several occasions management at the big steel firms were called in front of congress to explain their lack of competition in pricing.[8] In the auto industry, the U.S. Justice Department charged Ford and GM with collusion and charged the Big Three with conspiring to eliminate competition (Adams and Brock, 1995, p. 87).

One common theme in these prominent Rust Belt industries is that the threat of competition from abroad or new domestic entrants was minimal after the end of WWII, and set in only gradually. In 1945 the U.S. produced two thirds of the world's steel and accounted for half of world steel exports (Tiffany, 1988, pp. 117-120). The U.S. auto and rubber industries had similarly dominant positions, and estimates suggest that it wasn't until the 1970s when foreign competitors had productivity levels that rivaled those of the United States. Lieberman and Johnson (1999), for example, estimate that steel productivity in Japan was below that of the U.S. until the mid 1970s (and similar or higher afterwards; see Figure 2, p. 9). Lieberman, Lau, and Williams (1990) find a similar pattern for automobiles (see Figure 1, p. 1205.)

4. Simple Model

In this section we present a simple model which illustrates the main components of the theory. The model links the extent of competition in labor and output markets to investment and hence productivity growth. The model predicts that less competition in either market leads to lower productivity growth.

4.1. Environment

There is a stand-in household who has linear utility in an aggregate consumption good. The consumption good is produced using the constant-elasticity-of-substitution (CES) production function

$$Y = \left(\int_0^1 q(i)^{\frac{1}{2}} di \right)^2 \tag{2}$$

over a variety of goods indexed by i for $i \in [0,1]$. The household has measure one of labor units that it supplies to the labor market inelastically. All household income is then spent purchasing the

by the National Industrial Recovery Act (which was later outlawed). The manufacturers agreed to "cease and desist" without admitting any wrongdoing. See French (1991, p. 95).

[8] For example, in 1957 the Senate's antitrust committee directly accused the steel industry of anticompetitive pricing behavior, and called industry leaders to testify for six days. In a telling exchange between Senator Estes Kefauver and U.S. Steel chairman Roger Blough, Kefauver asked why all the major steel companies had the same price. Blough responded: "...if we offer to sell steel to a customer at the same price as a competitor offers to sell to the customer, that is very definitely a competitive price." According to Tiffany (1988), Kefauver and the rest of committee were thoroughly unconvinced, yet no punishment was ever sought for any steel producer.

various goods. Goods $i \in [0, \frac{1}{2})$ are produced in the "Rust Belt," and goods $i \in [\frac{1}{2}, 1]$ are produced in the "Sun Belt." These two regions differ in the nature of their competition in labor markets and output markets (as described below). Each good i is produced by an industry that has a single "lead" producer and, in the Sun Belt region, a competitive fringe.

Time is divided into two stages. In the first stage, each leader firm enters with productivity z and chooses how much investment, $x(i)$, to undergo. One can think of z as "technology capital", using the language of McGrattan and Prescott (2010), which they define as the "accumulated know-how from investments in R&D, brands and organizations," and $x(i)$ as the investments themselves. The investments can be made at cost $C(x)$, where $C(\cdot)$ is strictly convex and is such that $C(0) = 0$. After investment, the leader's productivity becomes $z(1+x(i))$, and the production function becomes

$$y(i) = z[1+x(i)]\ell(i) \tag{3}$$

where $y(i)$ and $\ell(i)$ represent the leader's output and labor input.

In the second stage, firms decide how much labor to hire and what price to charge, given their production function (3). In the Sun Belt, leader firms must Bertrand compete with the competitive fringe. In the Rust Belt, we assume the leader firms get to "block" the fringe from operating.[9] Thus, in the Sun Belt, leader firms pick the optimal price taking into consideration the fringe. In the Rust Belt, on the other hand, leaders face no competition and set an optimal monopolist markup.

The labor market in the Rust Belt is dominated by a single labor union that is the sole supplier of labor services. In order to produce any output, Rust Belt firms must not only pay each worker hired the competitive wage (normalized to one), but must also pay a fraction of their surplus to the labor union. The fraction of the surplus paid to the union is determined in Nash Bargaining, with the union's bargaining weight given by β. The labor market in the Sun Belt is competitive, in contrast, and each worker earns just the competitive wage.

4.2. Sun Belt Producer's Problem

In the Sun Belt, the first-stage (investment) problem of producer i is given by

$$\Pi_S(i) = \max_{x_S(i)} \left\{ \tilde{\pi}_S(x_S(i)) - C(x_S(i)) \right\} \tag{4}$$

[9] In the dynamic model in section 5 we allow the extent of blocking to be a continuous variable.

where $\tilde{\pi}_S(x_S(i))$ represents the *quasi-rents* earned in the second stage. The second-stage problem is to pick prices and labor input to maximize these quasi rents:

$$\tilde{\pi}_S(x_S(i)) = \max_{p_S(i),\, \ell_S(i)} \Big\{ p_S(i) y_S(i) - \ell_S(i) \Big\} \tag{5}$$

subject to

$$y_S(i) = z[1 + x_S(i)]\ell_S(i), \quad \text{and}$$
$$y_S(i) = I \cdot P \cdot [p_S(i)]^{-2}, \tag{6}$$

where equation (6) is the standard demand function under CES preferences. Variables I and P represent the (endogenous) total spending on all goods by the household and the aggregate price index, and are given by:

$$I = \int_0^{\frac{1}{2}} p_R(i) q_R(i) di + \int_{\frac{1}{2}}^1 p_S(i) q_S(i) di \quad \text{and}$$
$$P = \Big[\int_0^{\frac{1}{2}} p_R(i)^{-1} di + \int_{\frac{1}{2}}^1 p_S(i)^{-1} di \Big]^{-1}.$$

Since Sun Belt leaders must Bertrand compete with the competitive fringe, it follows that they limit price the fringe, charging a price of $p_S(i) = 1/z$.[10]

To understand better how the Sun Belt producers operate, it is useful to rewrite their first-stage problem after incorporating the optimal limit-pricing behavior. It is

$$\Pi_S(i) = \max_{x_S(i)} \Big\{ x_S(i) \ell_S(x(i)) - C(x_S(i)) \Big\} \tag{7}$$

where $\ell_S(x(i)) = I \cdot P \cdot z[1 + x_S(i)]^{-1}$. One can then see how investment is key to earning any profits at all; if the leader doesn't invest, she cannot price below the fringe, and hence earns no profits. Thus, the Sun Belt leaders rationale for investing is the escape-the-competition effects of e.g. Acemoglu and Akcigit (2011) and Aghion, Bloom, Blundell, Griffith, and Howitt (2005).

4.3. Rust Belt Producer's Problem

The Rust Belt producers' problem differs from the Sun Belt producers' problem in two ways. First, in output markets, the Rust Belt gets to block the competitive fringe and set a standard monopolist markup. Second, in labor markets, the Rust Belt must hire labor through a union with collective

[10] If investment among Sun Belt producers is sufficiently high in equilibrium, specifically if $x_S(i) > 1$, then Sun Belt producers choose a standard monopolistic markup. For expositional purposes we focus here on the case where $x_S(i) \leq 1$.

bargaining rights. The union supplies labor in exchange for the competitive wage plus a share of the producers' profits.

4.3.1. Collective Bargaining

Consider first the second-stage problem, once the investment decision $x_R(i)$ has been decided. The quasi-rents of firm i are

$$\tilde{\pi}_R(x_R(i)) = \max_{p_R(i),\ell_R(i)} \Big\{ p_R(i) y_R(i) - \ell_R(i) \Big\} \quad \text{where} \tag{8}$$

$$y_R(i) = z[1 + x_R(i)]\ell(i), \quad \text{and}$$

$$y_R(i) = I \cdot P \cdot [p_R(i)]^{-2}. \tag{9}$$

These quasi-rents are defined identically to those of the Sun Belt producers. The difference is that Rust Belt firms must bargain with the union over the *surplus* earned after subtracting investment costs from the quasi-rents. Formally, we write this surplus as

$$S(x_R(i)) = \tilde{\pi}_R(x_R(i)) - C\big(x_R(i)\big). \tag{10}$$

We assume that the union and each producer split the surplus according to Nash Bargaining, with the unions' bargaining weight represented by $\beta \in [0,1]$. Since the firms' investment is sunk, there is a key asymmetry between the bargaining position of the firm and that of the union. Specifically, the outside option of the firm (i.e. the firm's profits assuming no production takes place) is $-C\big(x_R(i)\big)$. The outside option of the union, on the other hand, is to simply supply labor competitively, in which case they earn zero: they earn none of the surplus but bear none of the costs of investment either.

Let $\hat{\theta}(x_R(i))$ be the share of the surplus going to the union as a function of $x_R(i)$. Then the Nash Bargaining solution satisfies:

$$\hat{\theta}(x_R(i)) = \arg\max_{\theta} \Big\{ \Big[(1-\theta) \cdot S(x_R(i)) + C\big(x_R(i), z_R, z_S\big) \Big]^{1-\beta} \cdot \Big[\theta \cdot S(x_R(i)) \Big]^{\beta} \Big\}, \tag{11}$$

and one can show that the solution is:

$$\hat{\theta}(x_R(i)) = \beta \Big[1 + \tfrac{C(x_R(i))}{\tilde{\pi}(x_R(i)) - C(x_R(i))} \Big]. \tag{12}$$

Equation (12) illustrates how the union's share of the surplus depends on the firms' investment. Only in the event that investment is zero do the workers end up with a share of the surplus equal to

their bargaining weight β. As long as there is any investment, workers end up with a share larger than β.

This result arises because the bargaining problem is a quintessential *hold-up problem.* Since the investment decision cannot be reversed once it has been made, the workers can hold up the firm and extract a larger share of the surplus ex-post.[11] We now turn to the optimal innovation decision of the firm, and show how this hold-up problem affects investment decisions ex-ante.

4.3.2. Investment and Production

Now consider the profit maximization problem of the Rust Belt producer. Given the bargaining solution above, the problem becomes:

$$\Pi_R(i) = \max_{x_R(i)} \left\{ [1 - \hat{\theta}(x_R(i))] \cdot S(x_R(i)) \right\} \tag{13}$$

subject to (9). In other words, firms pick investment to maximize their share of the surplus.

One key difference from the Sun Belt producers is that Rust Belt producers keep only a fraction $\hat{\theta}(x_R(i))$ of any surplus. The second key difference is that Rust Belt producers do not face a competitive fringe and simply choose their optimal price (taking prices of the other goods as given.) As is standard, these firms choose a price which gives them a constant markup (in this case of 100%) over marginal cost:

$$p_R(i) = 2(z[1 + x_R(i)])^{-1}. \tag{14}$$

It is useful to re-write the Rust Belt producer's first-stage (investment) problem incorporating their optimal price as

$$\Pi_R(i) = \max_{x_R(i)} \left\{ [1 - \hat{\theta}(x_R(i))] \cdot [\ell_R(i) - C(x_R(i))] \right\} \tag{15}$$

subject to $\ell_R(x(i)) = I \cdot P \cdot z[1 + x_R(i)]^{-1}$. Here, the firm earns a constant $\hat{\theta}(x_R(i))$ units of output per unit of labor input hired, reflecting the constant markup over marginal cost charged by the Rust Belt firm. Unlike the Sun Belt's equivalent problem in (7), the escape competition effect is absent. The Rust Belt firms' rationale for innovation is that a more efficient production technology increases demand for their variety.

[11] Van Reenen (1996) provides evidence that workers do in fact capture some of the surplus from innovations by their firms. Using a rich panel of firms of the United Kingdom, he shows firms that innovate tend to pay higher wages with a lag of roughly three years after innovating. He estimates that workers in innovating firms capture on average 20% to 30% of the quasi-rents generated by innovation.

4.4. Optimal Investment in Equilibrium

An equilibrium of the economy is a set of quantities and prices such that households and producers solve their problems taking prices (other than their own) as given, all firms in each region choose the same prices and quantities, and markets clear. We will drop the *i* index for equilibrium objects for convenience, and to distinguish equilibrium quantities with the choice variables of a single producer. One can show that the following is true in equilibrium.

Proposition 1 *Equilibrium investment is lower in the Rust Belt region.*

The proof is in the Appendix. To gain some intuition for the result, consider first the case when parameters are such that $x_S > 1$. One can think of this as being the case when investment costs are "sufficiently low." In this case, the Sun Belt producers are so much more productive than the competitive fringe that they choose to set a standard monopoly markup, just like Rust Belt producers.[12] One can combine the firms' first order conditions to show that optimal investment in equilibrium must satisfy the following equation:

$$C'(x_R) = (1-\beta)\, C'(x_S). \tag{16}$$

It follows therefore that $x_R < x_S$, since $\beta > 0$ and $C(\cdot)$ is convex. Here, the difference in innovation results only from the fact that labor manages to extract a fraction of the surplus (positively related to β) from Rust Belt producers. Absent this non-competitive behavior in labor markets, i.e. when $\beta = 0$, investment is identical in the two regions.

Consider next the case when parameters are such that $x_S < 1$. One can think of this as the case when investment costs are sufficiently high. Now Sun Belt producers limit price the competitive fringe, while Rust Belt firms choose the standard monopolist markup. In addition, Rust Belt firms still must bargain with labor over the surplus. Combining the firms' first order conditions this time yields:

$$C'(x_R) = (1-\beta)\left(\frac{1+x_S}{2}\right)^2 C'(x_S). \tag{17}$$

In this case it also must be true that $x_R < x_S$. There are now two reasons for the difference in equilibrium investment. As before, the $1-\beta$ term arises from the fact that the Rust Belt firms get to keep less than the total proceeds from investment. In addition, the $\left(\frac{1+x_S}{2}\right)^2$ term arises from the differences in output market competition, and this term is less than one as long as $x_S < 1$ in

[12] Bernard, Eaton, and Jensen (2003) have a similar result, where the most productive producer either sets a standard monopolist markup if it is much more productive than other firms, or limit prices the second most productive if the two have more similar productivty levels.

equilibrium, which is true if and only if the Sun Belt firms are actually limit pricing in equilibrium. If so, Rust Belt firms get to charge a higher markup even when innovating relatively less, while Sun Belt firms innovate more to escape the competition.

5. Dynamic Model

We now embed the main features of the simple static model into a richer dynamic model, that can be used for quantitative counterfactual experiments. The model differs mainly in that firm productivity and employment by region evolve endogenously over time.

5.1. Environment

There is a stand-in household whose preferences are given by

$$U = \sum_{t=0}^{\infty} \delta^t C_t \tag{18}$$

where δ is the discount factor and C_t is consumption of an aggregate consumption good. The resource constraint is that $C_t < Y_t$, where Y_t is production of the aggregate good. The aggregate good is produced using the CES production function

$$Y = \left(\int_0^1 q(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} \tag{19}$$

where the substitution elasticity between any pair of goods in the economy is σ. We assume that $\sigma > 1$, which implies that goods are gross substitutes. As before, each good is produced by a competitive monopolist located in one of two regions, the Rust Belt or the Sun Belt. The exogenous measure of Rust Belt goods is $\lambda \in (0,1)$, while the measure of goods in the Sun Belt is $1-\lambda$. Just as in the simple benchmark the production of each good requires a single input, labor, and the wage is normalized to unity each period.

Each period is divided into two stages. In the first stage, the firms decide how much investment to undertake. We assume that the cost function for investment is

$$C(x_j, Z_j) = x_j^{\gamma} \frac{\overline{c}\, z_j^{\sigma-1}}{\lambda \tilde{z}_R^{\sigma-1} + (1-\lambda)\tilde{z}_S^{\sigma-1}} \tag{20}$$

for $Z_j = (z_j, \tilde{z}_j, \tilde{z}_{-j})$, $\gamma > 1$, $\overline{c} > 0$ and $j \in \{R, S\}$. One desirable property of this cost function is that investment costs are increasing and convex in x. Moreover, the further the firm lags the "average" productivity level in the economy the cheaper it is to upgrade the current technology z_j. A second

desirable property, as we show later, is that this cost function delivers balanced growth when the the imperfections in labor and output markets are shut down.

The extent of competition is governed by two parameters each period, denoted β_t and μ_t, with $\beta_t \in [0,1]$ and $\mu_t \in [0,1]$ for all t. Parameter β_t represents the bargaining power of the workers in the Rust Belt at time t, with higher β_t meaning more bargaining power for workers. Parameter μ_t governs the extent of "monopoly power" in the Rust Belt at t (explained below), with higher μ_t representing more monopoly power. We assume that the complete sequence of $\{\beta_t, \mu_t\}_{t=0}^{\infty}$ is known with certainty to all agents in the model.

Both regions face a competitive fringe each period. In the Sun Belt, the fringe enters with productivity ϕz_S, where z_S is the initial productivity among Sun Belt producers, and the parameter $\phi > 0$ governs how effectively the fringe catches up to the leader firms each period. In the Rust Belt, the fringe begins the second stage with productivity $\phi z_R(1-\mu_t)$. The parameter μ captures the ease with which incumbents can block entry by potential challengers. One can think of this as arising from policies which protect incumbent producers, such as emphasized by Parente and Prescott (1999) and Herrendorf and Teixeira (2011).

5.2. Static Firm Problem

The firms' static profit maximization problem is similar to the one laid out in the simple static model of the previous section. Still, we spell it out completely here for clarity. In the first stage, the firm decides how much to invest. In the second stage, the firms decides what price to set and how much labor to hire in order to maximize their quasi-rents. Clearly, forward-looking producers anticipate the quasi-rents in stage two associated with any given investment decision. So let us describe the firm's problem starting with stage two.

Consider a Sun Belt firm who enters the period with productivity z_S and has chosen investment level x_S. Assume that all the other Sun Belt firms have productivity $\tilde{z}_S$ and have chosen investment $\tilde{x}_S$, which could be equal to z_S and x_S (and will be in equilibrium). Finally, assume that all Rust Belt producers have productivity $\tilde{z}_R$ and have chosen investment $\tilde{x}_R$. To keep the notation tidy, we define $Z_S \equiv (z_S, \tilde{z}_S, \tilde{z}_R)$ and $X_S \equiv (x_S, \tilde{x}_S, \tilde{x}_R)$. Whenever possible, we also drop the firm label $i \in [0,1]$. The static profit maximization problem of the Run Belt firm is to maximize the quasi-rents:

$$\tilde{\pi}_S(Z_S, X_S) = \max_{p_S,\, \ell_S} \left\{ p_S y_S - \ell_S \right\} \tag{21}$$

subject to $y_S = z_S[1+x_S]\ell_S$ and $y_S = I \cdot P^{\sigma-1} \cdot p_S^{-\sigma}$, which are the production function and standard demand function under CES preferences. As before, I and P represent total spending on all goods

by the household and the aggregate price index, respectively:

$$I = \int_0^{\lambda} p_R(i) q_R(i) di + \int_{\lambda}^{1} p_S(i) q_S(i) di$$
$$P = \Big[\int_0^{\lambda} p_R(i)^{1-\sigma} di + \int_{\lambda}^{1} p_S(i)^{1-\sigma} di \Big]^{\frac{1}{1-\sigma}}.$$

Since Sun Belt leaders must Bertrand compete with the competitive fringe, it follows that they limit price the fringe and charge $p_S(i) = \frac{1}{\phi z_S}$.[13]

Now consider a Rust Belt firm who enters the period with productivity z_R and has chosen investment level x_R, while all other Rust Belt producers have productivity $\tilde{z}_R$ and investment $\tilde{x}_R$. Assume that all Sun Belt producers have productivity $\tilde{z}_S$ and have chosen investment $\tilde{x}_S$. As we did for the Sun Belt, let us define $Z_R \equiv (z_R, \tilde{z}_R, \tilde{z}_S)$ and $X_R \equiv (x_R, \tilde{x}_R, \tilde{x}_S)$. Quasi-rents of the Rust Belt are given by

$$\tilde{\pi}_R(Z_R, X_R; \mu) = \max_{p_R, \ell_R} \Big\{ p_R y_R - \ell_R \Big\} \tag{22}$$

subject to $y_R = z_R[1 + x_R]\ell_R$ and $y_R = I \cdot P^{\sigma-1} \cdot p_R^{-\sigma}$. The additional argument in the Rust Belt producer's profit function, μ, reflects the difference in the limit price compared to a Sun Belt producer. We can write the surplus after investment as:

$$S(Z_R, X_R; \mu) = \tilde{\pi}_R(Z_R, X_R; \mu) - C\big(x_R, Z_R\big). \tag{23}$$

The union and firm split the surplus according to Nash Bargaining. The union's bargaining weight is $\beta \in (0,1)$. As before, let $\hat{\theta}(X_R, Z_R)$ be the share of the surplus going to the union as a function of the firm's investment decision $x_R(i)$. One can show that the Nash Bargaining solution is for the workers to get a fraction

$$\hat{\theta}(x_R, Z_R; \beta, \mu) = \beta \Big[1 + \tfrac{C(x_R, Z_R)}{\tilde{\pi}_R(Z_R, X_R; \mu) - C(x_R, Z_R)} \Big].$$

As in the simple static model, the bargaining solution results from a hold-up problem, where the workers extract a larger share of the surplus than they otherwise would. The reason is again the asymmetry in outside options in the bargaining process. If bargaining "breaks down," then the workers simply supply labor at the competitive wage. The firms, on the other hand, must bear the investment cost, which is sunk, but produce nothing.

[13] For expositional purposes we focus on the case where investment in equilibrium is "sufficiently low" such that it is optimal for Sun Belt producers to limit price the fringe. More generally, they either limit price or set a standard monopolist markup, depending on how much investment they undertake in equilibrium.

5.3. Dynamic Firm Problem

We now consider the dynamic problem of the firms. The Bellman equation that describes a Sun Belt producer's problem is:

$$V_S(Z_S;\beta,\mu) = \max_{x_S}\left\{\tilde{\pi}_S(Z_S,X_S) - C(x_S,Z_S) + \delta V_S\left(Z_S;\beta',\mu'\right)\right\} \tag{24}$$

where $Z_S' = \left(z_S(1+x_S), \tilde{z}_S(1+\tilde{x}_S), \tilde{z}_R(1+\tilde{x}_R)\right)$. The Sun Belt producer picks the amount of investment each period to maximize quasi rents minus investment costs plus the discounted value of future profits.

Analogously, the Rust Belt producer's Bellman equation is:

$$V_R(Z_R;\beta,\mu) = \max_{x_R}\left\{\left[1-\hat{\theta}(x_R,Z_R;\beta,\mu)\right]\left[\tilde{\pi}_R(Z_R,X_R,\beta;\mu) - C(x_R,Z_R)\right] + \delta V_R\left(Z_R';\beta',\mu'\right)\right\} \tag{25}$$

where $Z_R' = \left(z_R(1+x_R), \tilde{z}_R(1+\tilde{x}_R), \tilde{z}_S(1+\tilde{x}_S)\right)$. β' and μ' denote next period's exogenous labor and product market frictions. The Rust Belt producer picks investment to maximize its share of current period profits (i.e. quasi rents minus investment costs) plus the discounted value of future profits. Its share is $1-\hat{\theta}(x_R,z_R,\tilde{z}_R,z_S)$, which is determined by the Nash bargaining.

5.4. Dynamics under Full Competition

We define the situation where $\beta = \mu = 0$ for the current and future periods as "full competition." Analyzing the case of full competition is convenient for gaining intuition, as the dynamics are particularly clean when both β and μ are zero. In particular, one can show that the following is true:

Proposition 2 *Under full competition, the economy is on a balanced growth path where (i) investment is some positive value x in each region each period, (ii) output and consumption per worker grow at rate of* $(1+x)$ *each period, (iii) the employment and output shares of the Rust Belt are constant each period, and (iv) the optimal investment x also solves the static model in Section 4 with* $\beta = 0$.

The proof is in the Appendix. Proposition 2 is useful for several reasons. First, it shows that absent the non-competitive conditions in labor and output markets in the Rust Belt, the economy is essentially a standard endogenous growth model. Second, it shows that the Rust Belt decline only occurs under the non-competitive conditions. Once these are removed, the regional shares of economy activity are constant from one period to the next. Third, it shows that optimal investment, x, is the same in each region each period. One can show x is given by the solution the following

non-linear equation

$$(1+x)^{-1} = \gamma \cdot \overline{c} \cdot x^{\gamma-1}$$

One can further characterize the equilibrium of the economy under full competition to show that period profits (i.e. quasi rents minus investment costs) are the same each period. This implies that the value functions for firms in each region are simply an infinite sum of the period profits. We formalize this as:

Proposition 3 *Under full competition, the value of a firm of type $j \in \{R,S\}$ is given by*

$$V_j(Z_j) = \frac{\pi_j(x)}{1-\delta}$$

where x is optimal investment and $\pi_j(x)$ is the period profits, given by

$$\pi_j(x) = \frac{z_j^{\sigma-1}}{\lambda z_R^{\sigma-1} + (1-\lambda) z_S^{\sigma-1}} \left(x - x^{\gamma}\right).$$

The proof is in the Appendix. Proposition 3 is useful mostly in that it pins down the value of the firm in closed form. This makes for transparent long-run properties of the model, which allows one to work backwards to solve the model under imperfect competition.

5.5. Dynamics under Imperfect Competition

We define the situation where either $\beta > 0$ or $\mu > 0$ for the current period as "imperfect competition." One can show (proposition coming soon) that if investment is lower in the Rust Belt than the Sun Belt in the current period, then the employment share in the Rust Belt declines between the current and following period. The reason is simple. Less investment means that he relative price of the Rust Belt goods' rises, and because goods are gross substitutes consumers demand relatively more of the cheaper Sun Belt goods. Thus, as in Ngai and Pissarides (2007), employment flows to the Sun Belt.

6. Quantitative Analysis

We now turn to a quantitative analysis of the dynamic model. The basic question we ask is how large of a decline in the Rust Belt's employment share the model predicts over the period 1950 to 2000. We calibrate the extent of competition faced by the Rust Belt using evidence on wage

premiums and markups. We find that the model predicts a large decline in the Rust Belt, explaining on the order of one-half the decline present in the data.

6.1. Parameterization

We set a model period to be five years. We set the discount rate to be $\delta = 0.96^5$ so as to be consistent with a 4% interest rate per year. For the elasticity of substitution we choose a value of $\sigma = 2$, which consistent with the work of Broda and Weinstein (2006), who estimate elasticities of substitution between a large number of goods at various levels of aggregation. They find that the median elasticity is at least 2.7, depending on the time period and level of aggregation, and the tenth percentile elasticities are in the range of 2.0. Our choice is on the conservative end of their estimates.

We calibrate the remaining parameters jointly. These are the sequences $\{\beta_t, \mu_t\}_{t=0}^{\infty}$, governing the extent of competition in labor and output markets, ϕ, which governs catch-up of the fringe, λ, which is the initial share of goods produced in the Rust Belt, and the two parameters of the investment-cost function: γ and $\overline{c}$.

Table 1: Rust Belt Wage Premium and Markups

	Wage Premium	Markup
1950	0.11	0.25
1960	0.11	0.25
1970	0.11	0.25
1980	0.10	0.22
1990	0.05	0.18
2000	0.04	0.15

The Wage Premium is measured as the ratio of wages in the Rust Belt region to the rest of the country. It is calculated using the census micro data from IPUMS. The Markup is based on the estimates of Collard-Wexler and De Loecker (2012) for the steel industry.

The moments we target are as follows. First, we target a wage premium from 1950 to 2000 that matches our estimates from the census data. We calculate the premium as the ratio of average wages in the Rust Belt to the rest of the country. The premium, given in Table 1, starts out at 11% in 1950 and stays there until 1970, falls to 10% in 1980, 5% in 1990 and then 4% in 2000. We assume a wage premium of zero for all subsequent periods.

Second, we target a markup of 25% in the Rust Belt in 1950 through 1970, falling to 22% in 1980,

18% in 1990 and 15% in 2000. This path is chosen based on the estimated markups of U.S. steel producers over the period calculated by Collard-Wexler and De Loecker (2012). They estimate that vertically integrated producers, who were located almost entirely in the Rust Belt, had average markups of 25% until the 1980s, where they fell steadily until around 15% by 2000 (see Figure 4, pg 33.) For subsequent periods we assume a markup that is the same in the Rust Belt and Sun Belt.

The remaining moments we target are a markup in the Sun Belt of 10%, an initial employment share in the Rust Belt of 44%, an aggregate investment-to-GDP ratio of 8%, and a long-run growth rate of 2% per year. The average markup in the Sun Belt is consistent with what Collard-Wexler and De Loecker (2012) estimate for 2000 among minimill steel producers (most of which were located in the U.S. South.) The initial employment share of the Rust Belt is from Figure 1 of the current paper, calculated using census data. The aggregate investment-to-GDP ratio is the average sum of investments in R&D, advertising and organization divided by GDP, as reported by McGrattan and Prescott (2010). The long-run growth rate is taken to be the average growth rate over the postwar period.

The parameter values implied by the calibration are $\phi = 1.02$, $\lambda = 0.52$, $\gamma = 1.7$ and $\bar{c} = 2.6$. The bargaining power parameters start out at $\beta_{1950} = 0.23$ and fall to $\beta_{2000} = 0.138$. The monopoly power parameters start at $\mu_{1950} = 0.167$ and fall to $\mu_{2000} = 0.080$. All subsequent values of β_t and μ_t are set to zero.

6.2. Quantitative Results

Figure 4 displays the model's predictions for the employment share in the Rust Belt from 1950 to 2000. Several points are worth noting from the Figure. First, the model predicts a large decline in the Rust Belt's employment share, as in the data. The model predicts a drop of 8 percentage points, from 44 percent down to 36 percent. The data has a drop of 16 percentage points, from 44 percent down to 28 percent. By this metric, the model explains around one-half the decline of the Rust Belt.

The second feature worth noting is that the model's predicted decline is more pronounced between 1950 and 1970, as in the data. The model predicts a drop of 6 percentage points, from 44 percent down to 38 percent, while the actual drop was 10 percentage points (down to 33 percent). In the next three decades, from 1970 to 2000, the Rust Belt's employment share declined just 5 percentage points. The model also predicts a less pronounced drop over this period equalling 2 percentage points, from 38 percent down to 36 percent.

The reason the model predicts a sharper drop between 1950 and 1970 is that competitive pressure was weaker over this period in the model. Once competition is increased in the model, as it is in

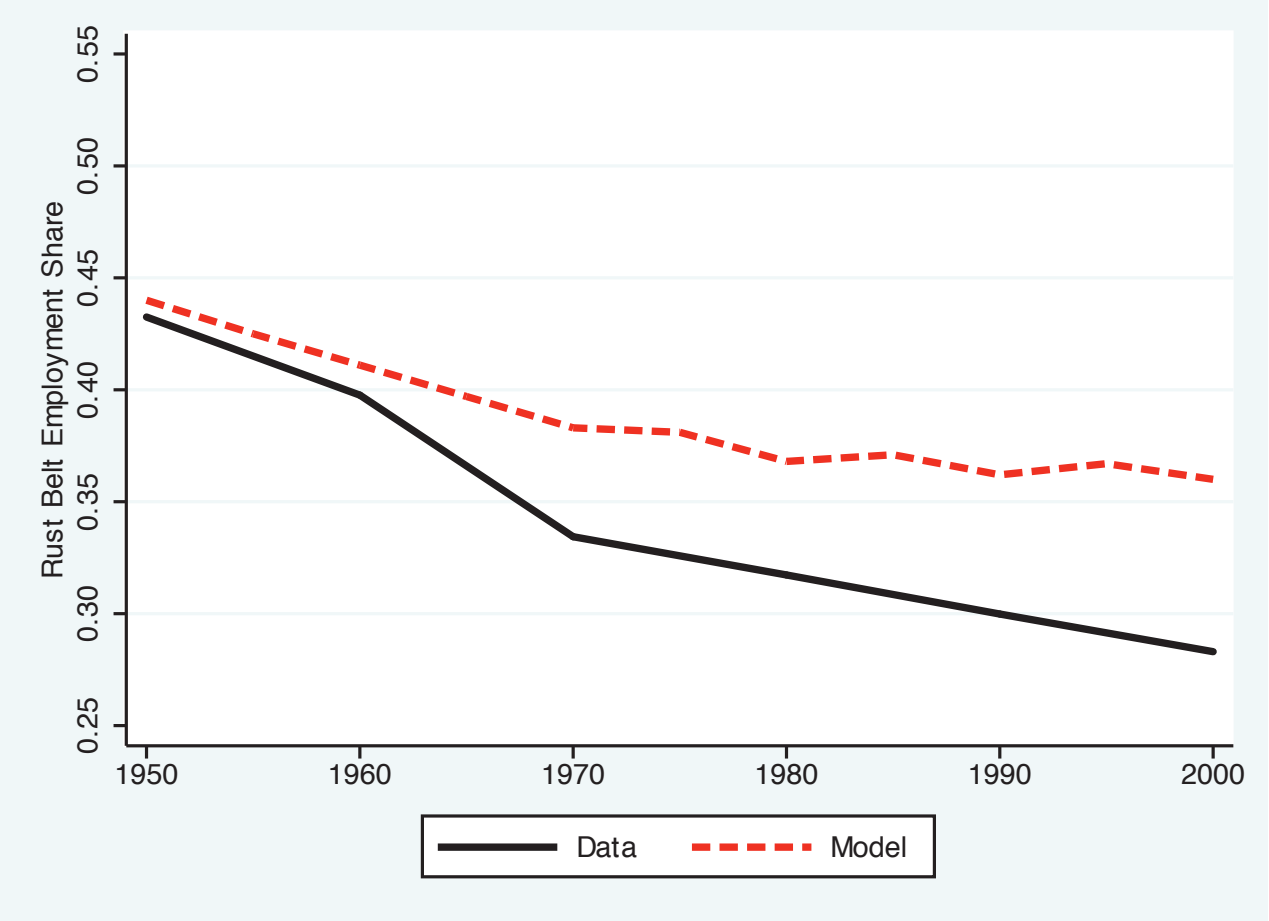


Figure 4: The Rust Belt's Employment Share: Model and Data

the period after 1970, the Rust Belt's decline abates.

6.3. Investment and Productivity Growth

Why does the model predict such a large decline in the Rust Belt's employment share? The driving force behind the model's prediction is the lower investment rate in the Rust Belt than the Sun Belt. The model predicts that investment expenditures averaged 5% of output in the Rust Belt, compared to 11% in the Sun Belt. This translates into average annualized productivity growth of 1.3% in the Rust Belt and 2.3% in the Sun Belt. Worth noting is that predicted productivity growth is lowest in the early period in the Rust Belt, at 1.2% per year from 1950 to 1980, and rising to 1.5% after 1980. In the Sun Belt productivity growth rates were 2.3% pre 1980 and 2.2% afterwards.

7. Testing the Model's Predictions

This section assesses the model's predictions that rates of investment and productivity growth were systematically lower in Rust Belt industries than those located elsewhere.

7.1. Investment and Technology Adoption

In the model, investments represent expenditures that lead to productivity increases in the future. One reasonable proxy for such investments are expenditures on research and development (R&D). Evidence from the 1970s suggests that R&D expenditures were lower in key Rust Belt industries, in particular steel, automobile and rubber manufacturing, than in other manufacturing industries. According to a study by the U.S. Office of Technology Assessment (1980), the average manufacturing industry had R&D expenditures totaling 2.5% of total sales in the 1970s. The highest rates were in communications equipment, aircraft and parts, and office and computing equipment, with R&D representing 15.2%, 12.4% and 11.6% of total sales, respectively. Auto manufacturing, rubber and plastics manufacturing, and "ferrous metals," which includes steelmaking, had R&D expenditures of just 2.1%, 1.2% and 0.4% of total sales. These data are qualitatively consistent with the model's prediction that investment rates were lower in the Rust Belt than elsewhere in the United States.[14]

Another proxy for productivity-enhancing investment activity is the rate of adoption of key productivity-enhancing technologies. For the U.S. steel industry before 1980, the majority of which was in the Rust Belt, there is a strong consensus that adoption rates of the most important technologies lagged far behind where they could have been (Adams and Brock, 1995; Adams and Dirlam, 1966; Lynn, 1981; Oster, 1982; Tiffany, 1988; Warren, 2001). The two most important new technologies of the decades following the end of WWII were the basic oxygen furnace (BOF) and the continuous casting method. Figure A.3 shows adoption rates of continuous casting methods in the United States, Japan and several other leaders in steel production. Two things are worth noting from this figure. First, the United States was a laggard, with only 15% of its capacity produced using continuous casting methods, compared to a high of 51% in Japan, by 1978. Second, this was the period where large integrated steel mills of the Rust Belt dominated production. Putting these two observations together implies that the Rust Belt lagged far behind in the adoption of one important technology over the period.[15]

[14] Several sources explicitly link the lack of innovation back to a lack of competition. For example, about the U.S. steel producers Adams and Brock (1995) state that "their virtually unchallenged control over a continent-sized market made them lethargic bureaucracies oblivious to technological change and innovation. Their insulation from competition induced the development of a cost-plus mentality, which tolerated a constant escalation of prices and wages and a neglect of production efficiency (page 93). "

[15] In the 1980s and afterward, the U.S. steel industry made large investments in a new technology, the minimill,

There is also agreement that the U.S. steel industry had ample opportunities to adopt the new technologies and chose not to do so. For example Lynn (1981) states that "the Americans appear to have had more opportunities to adopt the BOF than the Japanese when the technology was relatively new. The U.S. steelmakers, however, did not exploit their opportunities as frequently as the Japanese." Regarding the potential for the U.S. Steel Corporation to adopt the BOF, Warren (2001) describes the 1950s and 1960s as "a period of unique but lost opportunity for American producers to get established early in the new technology."[16]

Similar evidence can be found for the rubber and automobile manufacturing industries. In rubber manufacturing, Rajan, Volpin, and Zingales (2000) and French (1991) argue that U.S. tire manufacturers missed out on the single most important innovation of the postwar period, which was the radial tire, adopting only when it was too late (in the mid 1980s). The big innovator of the radial tire was (the French firm) Michelin (in the 1950s and 1960s). According to French (1991), most of the U.S. rubber tire producers hadn't adopted radials even by the 1970s, even as Michelin drastically increased its U.S. market share.[17]

About the automobile industry, Halberstam (1986) writes

> Since competition within the the [automobile manufacturing] industry was mild, there was no incentive to innovate; to the finance people, innovation not only was expensive but seemed unnecessary... From 1949, when the automatic transmission was introduced, to the late seventies, the cars remained remarkably the same. What innovation there was came almost reluctantly (p. 244)

The lack of innovation by the auto industry is noted also by e.g. Adams and Brock (1995), Ingrassia (2011) and Vlasic (2011).

7.2. Productivity Growth

Direct measures of productivity growth by region do not exist unfortunately. Nevertheless, we can assess the model's predictions for productivity growth in the Rust Belt and Sun Belt by comparing

which used an electric arc furnace to turn used steel products into raw steel for re-use. Virtually all of these adoptions were made outside of the Rust Belt region, and in the U.S. South in particular. See Collard-Wexler and De Loecker (2012) and the references therein.

[16] According to Ankl and Sommer (1996), an engineer at the U.S. Steel Company visited the Austrian Linz BOF plant in 1954 and brought back a favorable report on the prospects of the BOF. Management at U.S. Steel vetoed this line of research and reprimanded the engineer for making an unauthorized visit to the Austrian firm (pp 161-162.)

[17] Interestingly, French (1991) claims that all the new radial plants, when they were eventual built, were built in the Midwest and South. Akron, "the Rubber City," stopped making passenger automobile tires in 1978, truck tires in 1984 and aircraft tires in 1987.

Table 2: TFP Productivity Growth by Individual Rust Belt Industries

	Annualized Growth Rate, %		
	1958-1980	1980-2000	1958-2000
Iron and Steel Foundries	0.0	0.5	0.2
Machinery, Misc	−0.4	−0.1	−0.2
Motor Vehicles	1.0	0.2	0.6
Railroad Equipment	1.0	−0.3	0.3
Rubber Products	−0.2	2.5	1.1
Steel Mills	0.4	0.9	0.7
Rust Belt Average	0.3	0.6	0.4
U.S. Economy	2.0	1.4	1.8

Note: Rust Belt Industries are defined as those industries whose employment shares in the Rust Belt MSAs are more than one standard deviation higher than the mean in both 1950 and 2000. Source: Author's calculations using NBER CES productivity database, U.S. census data from IPUMS, and the BLS.

estimates of productivity growth in industries that were prominent in the Rust Belt region over period 1950 to 2000 to productivity growth in the rest of the economy.

Concrete estimates of productivity growth by industry are available from the NBER CES database.[18] By matching their industries (by SIC codes) to those available to us in our IPUMS census data (by census industry codes), we are able to compute the fraction of all employment in each industry that is located in Rust Belt MSAs in each year. We define ''Rust Belt industries" as all those industries with employment shares in Rust Belt MSAs greater than one standard deviation above the mean in both 1950 and 2000. The industries that make the cut are Iron and Steel Foundries, Machinery (Misc), Motor Vehicles, Railroad Equipment, Rubber Products, and Steel Mills.

Table 2 provides estimates of total-factor productivity (TFP) growth per year in these industries over several time horizons. As a frame of reference, we compute TFP for the U.S. economy as a whole as the Solow Residual from a Cobb-Douglas production function with labor share two-thirds and aggregate data from the BEA. The right-most column shows the entire period of data availability, namely 1958-2000. TFP growth was lower in every Rust Belt industry than for the U.S. economy as a whole. The highest growth was in Rubber Products, which grew at 1.1% per year, while the lowest was in Machinery, which grew at -0.2% per year. The U.S. economy, on the

[18] Data and a detailed description of the data are available here: http://www.nber.org/nberces/.

other hand, had far higher TFP growth of 1.8% per year over this period.

The first and second two columns show TFP growth by industry in the periods 1958-1980 and 1980 to 2000. We chose this breakdown because we observed that productivity in several of these industries increased after around 1980. Furthermore, the evidence of Schmitz (2005) and Dunne, Klimek, and Schmitz (2010) suggests that the early 1980s were a time when competitive pressure in the Great Lakes region may have increased substantially.[19]

The first two columns show that in four of the six industries – Iron and Steel Foundries, Machinery, Rubber Products, and Steel Mills – there is evidence that productivity increased in the period after 1980. This is consistent with the productivity pickup found in the model in the latter part of the period.

For the automobile industry, international evidence also supports the idea that productivity growth was lower than it otherwise might have been. Table A.2 shows a simple measure of productivity – vehicles produced per worker – for the big three U.S. auto producers and two prominent Japanese producers, Nissan and Toyota. On average, the U.S. producers increased output per worker by about 25% over the period 1960 to 1983. Over the same period, the Japanese producers increased output per worker by over 300%. For example General Motors went from 8 cars per worker in 1960 to 11 in 1983, while Nissan went from 12 to 42. These productivity estimates are crude at best given that they ignore capital, differences in the size and quality of vehicle and so forth. Nevertheless, they show dramatic differences in output per worker over the period, with the U.S. far behind in terms of apparent productivity growth.

8. Alternative Hypotheses

There are a number of other plausible stories for why the Rust Belt declined. The current paper has explored one hypothesis and assessed its quantitative importance, finding a large effect. Nothing in the current paper suggests that other economic forces did not potentially play important roles as well. Still, it is worth discussing other prominent hypotheses and making the case that these can at best serve as partial answers to why the Rust Belt declined so dramatically.

The advent of air conditioning. As any resident of Arizona or Florida can attest, the increasing population of their states in recent years would not have been possible without air conditioning. In the early part of the 20th century air conditioning largely did not exist; it became widespread only after the end of WWII. Certainly some of the movement of economic activity out of the Rust Belt

[19] Both of these papers argue that transportation costs for foreign competitors (in the iron ore and cement industries) may have increased in the early 1980s. The papers also both show evidence of a dramatic increase in productivity starting in the early 1980s.

can be attributed to the advent of air conditioning.

Yet even in regions where temperature differences are negligible, one can see big differences in economic performance due to differences in competition. Using geographic data from U.S. counties, Holmes (1998) looks along the borders between states that have right-to-work laws (preventing unionized plants from forcing new workers to join the union) and states that do not. One example, for concreteness, is the border between Iowa (a right-to-work state) and Illinois (a non right-to-work state which has historically been highly unionized.)

He finds that counties in the right-to-work states (within 25 miles of the border) had on average 101% growth in manufacturing employment between 1947 and 1992. For counties on just on the other side of the border, employment growth was just 62% over the same period. Differences between western Rust Belt states and the bordering great plains states were even larger. There, border counties in right-to-work states (such as Iowa) had manufacturing employment growth of 104%, while border counties in neighboring states (such as Illinois) had employment growth of just 54%. Given that there are essentially no differences in temperature or geographic terrain between these sets of counties, it must be that the vast differences in employment growth is due to differences in state policies. One prominent candidate policy of course is the extent to which competition in labor market is protected, though e.g. right-to-work legislation.

Structural change. One possible story why the Rust Belt declined was that the region was just suffering from the larger economic phenomenon of structural change. This could be the case for example, if preferences are such that the income elasticity of demand for services is larger than one, meaning that general economic growth leads to a rise of services and a decline in manufacturing. The rise of services is certainly a robust feature of the data, as is the general decline in manufacturing as a share of total employment. But as Figure 1 and Figure A.1 show, *even within the manufacturing sector* the Rust Belt's share of employment declined dramatically over this period. Thus, the Rust Belt's decline could not entirely due to a simple structural change story. Instead, economic forces within the manufacturing sector must have lead to the divergent path between manufacturing in the Rust Belt and the rest of the country.

9. Conclusion

While the U.S. economy as a whole experience growth of just under two percent per year over the postwar period, there was substantial variation in growth experiences across regions within the country. In this paper we document that the wage premium earned by a region's workers on average in 1950 is a very good predictor of subsequent growth in wages and employment, with lower growth rates occurring in regions with higher wage premiums in 1950. Furthermore, many

of the regions with the highest premiums and worst economic performance are concentrated in what is often called the Rust Belt: the manufacturing zone around the Great Lakes.

We use this fact to build a theory of the decline of the Rust Belt. Our theory is that a lack of competition was behind the Rust Belt's poor economic performance. We argue that the high wage premiums earned by workers in the Rust Belt region reflected non-competitive behavior in labor markets, with powerful labor unions active in many of the major Rust Belt industries, such as steel, automobile and rubber manufacturing. We then cite direct evidence that output markets were non-competitive as well, with just several large dominating each of the major Rust Belt industries.

We formalize our theory in a dynamic general equilibrium model, in which the strength of competition in labor and output markets determines the extent to which firms innovate and increase productivity. Non-competitive labor markets lead to a "hold up" problem, which discourage firms from investing. Non-competitive output markets eliminate the firm's incentive to invest in order to escape the competition. A plausibly calibrated version of the model predicts roughly one-half of the decline found in the data. The model also predicts that the Rust Belt lagged behind in investment in new technologies and productivity growth. Several types of evidence from prominent Rust Belt industries support these predictions.

References

ACEMOGLU, D., AND U. AKCIGIT (2011): "Intellectual Property Rights Policy, Competition and Innovation," *Journal of the European Economic Association*, 10(1), 1–42.

ACIKGOZ, O. T., AND B. KAYMAK (2012): "The Rising Skill Premium and Deunionization in the United States," Unpublished Manuscript, Universite de Montreal.

ADAMS, W., AND J. BROCK (eds.) (1995): *The Structure of American Industry*. Prentice-Hall, Inc.

ADAMS, W., AND J. B. DIRLAM (1966): "Big Steel, Invention, and Innovation," *Quarterly Journal of Economics*, 80(2), 167–189.

AGHION, P., N. BLOOM, R. BLUNDELL, R. GRIFFITH, AND P. HOWITT (2005): "Competition and Innovation: An Inverted U Relationship," *Quarterly Journal of Economics*.

ANKL, R., AND E. SOMMER (1996): *The Role of Management in the Decline of the American Steel Industry*.

BERNARD, A. B., J. EATON, AND J. B. JENSEN (2003): "Plants and Productivity in International Trade," *American Economic Review*, 93(4), 1268–1290.

BLANCHARD, O., AND L. KATZ (1992): "Regional Evolutions," *Brookings Papers on Economic Activity*, 1992(1).

BLANCHFLOWER, D. G., AND A. BRYSON (2004): *The Union Wage Premium in the US and the UK*. Centre for Economic Performance.

BLOOM, N., M. DRACA, AND J. V. REENAN (2011): "Trade Induced Technical Change? The Impact of Chinese Imports on Innovation, IT and Productivity," NBER Working Paper 16717.

BRIDGMAN, B. (2011): "Competition, Work Rules and Productivity," Unpublished Manuscript, Bureau of Economic Analysis.

BRODA, C., AND D. WEINSTEIN (2006): "Globalization and the Gains from Variety," *Quarterly Journal of Economics*, 121(2).

CARRINGTON, W., AND A. ZAMAN (1994): "Interindustry Variation in the Costs of Job Displacement," *Journal of Labor Economics*, 12(2), 243–275.

COLE, H. L., AND L. E. OHANIAN (2004): "New Deal Policies and the Persistence of the Great Depression: A General Equilibrium Analysis," *Journal of Political Economy*, 112(4), 779–816.

COLLARD-WEXLER, A., AND J. DE LOECKER (2012): "Reallocation and Technology: Reallocation and Technology: Evidence from the U.S. Steel Industry," Unpublished Manuscript, New York University.

CRANDALL, R. W. (1981): *The U.S. Steel Industry in Recurrent Crisis*. Brookings Institution Press.

DINLERSOZ, E., AND J. GREENWOOD (2012): "The Rise and Fall of Unions in the U.S.," Unpublished Manuscript, University of Pennsylvania.

DUNNE, T., S. KLIMEK, AND J. A. SCHMITZ (2010): "Competition and Productivity: Evidence from the Post WWII U.S. Cement Industry," Unpublished Manuscript, U.S. Census Bureau.

FEYRER, J., B. SACERDOTE, AND A. D. STERN (2007): "Did the Rust Belt Become Shiny? A Study of Cities and Counties That Lost Steel and Auto Jobs in the 1980s," *Brookings-Wharton Papers on Urban Affairs*, pp. 41–102.

FRENCH, M. J. (1991): *The U.S. Tire Industry*. Twayne Publishers, Boston.

GLAESER, E. L., AND G. A. PONZETTO (2007): "Did the Death of Distance Hurt Detroit and Help New York?," Unpublished Manuscript, Harvard University.

GOLDFIELD, M. (1987): *The Decline of Organized Labor in the United States*. The University of Chicago Press, Chicago.

HALBERSTAM, D. (1986): *The Reckoning*. William Morrow and Company, Inc.

HERRENDORF, B., AND A. TEIXEIRA (2011): "Barriers to Entry and Development," *International Economic Review*, 52(2), 573–602.

HOLMES, T. J. (1998): "The Effect of State Policies on the Location of Manufacturing: Evidence from State Borders," *Journal of Political Economy*, 106(4), 667–705.

HOLMES, T. J., AND J. A. SCHMITZ (2010): "Competition and Productivity: A Review of Evidence," *Annual Review of Economics*, 2, 619–642.

INGRASSIA, P. (2011): *Crash Course*. Random House, New York.

JACOBSON, L. S., R. J. LALONDE, AND D. G. SULLIVAN (1993): "Earnings Losses of Displaced Workers," *American Economic Review*, 83(4), 685–709.

LIEBERMAN, M. B., AND D. R. JOHNSON (1999): "Comparative Productivity of Japanese and U.S. Steel Producers, 1958-1993," *Japan and the World Economy*, 11, 1–27.

LIEBERMAN, M. B., L. J. LAU, AND M. D. WILLIAMS (1990): "Firm-Level Productivity and Management Influence: A Comparison of U.S. and Japanese Automobile Producers," *Management Science*, 36(10), 1193–1215.

LYNN, L. (1981): "New Data on the Diffusion of the Basic Oxygen Furnace in the U.S. and Japan," *Journal of Industrial Economics*, 30(123-135).

MCGRATTAN, E. R., AND E. C. PRESCOTT (2010): "Technology Capital and the U.S. Current Account," *American Economic Review*, 100(4), 1493–1522.

NGAI, R. L., AND C. A. PISSARIDES (2007): "Structural Change in a Multisector Model of Growth," *American Economic Review*, 97(1).

OSTER, S. (1982): "The Diffusion of Innovation among Steel Firms: The Basic Oxygen Furnace," *Bell Journal of Economics*, 13(1), 45–56.

PARENTE, S. L., AND E. C. PRESCOTT (1999): "Monopoly Rights: A Barrier to Riches," *American Economic Review*, 89(5), 1216–1233.

PAVCNIK, N. (2002): "Trade Liberalization, Exit and Productivity Improvement: Evidence from Chilean Plants," *Review of Economic Studies*, 69(1), 245–276.

RAJAN, R. G., P. VOLPIN, AND L. ZINGALES (2000): "The Eclipse of the U.S. Tire Industry," in *Mergers and Productivity*, ed. by S. N. Kaplan, pp. 51–92. University of Chicago Press.

RUGGLES, S. J., T. ALEXANDER, K. GENADEK, R. GOEKEN, M. SCHROEDER, AND M. SOBEK (2010): "Integrated Public Use Microdata Series: Version 5.0," [Machine-readable database]. Minneapolis: University of Minnesota.

SCHMITZ, J. A. (2005): "What Determines Productivity? Lessons from the Dramatic Recovery of the U.S. and Canadian Iron Ore Industries Following Their Early 1980s Crisis," *Journal of Political Economy*, 113(3), 582–625.

——— (2012): "New and Larger Costs of Monopoly and Tariffs," Federal Reserve Bank of Minneapolis Staff Report 468.

SYVERSON, C. (2011): "What Determines Productivity?," *Journal of Economic Literature*, 49(2), 326–365.

TASCHEREAU-DUMOUCHEL, M. (2012): "The Union Threat," Unpublished Manuscript, The Wharton School of the University of Pennsylvania.

TIFFANY, P. A. (1988): *The Decline of American Steel*. Oxford University Press.

U.S. OFFICE OF TECHNOLOGY ASSESSMENT (1980): "Technology and Steel Industry Competiveness," U.S. Government Printing Office.

VAN REENEN, J. (1996): "The Creation and Capture of Rents: Wages and Innovation in a Panel of U.K. Companies," *Quarterly Journal of Economics*, 111(1), 195–226.

VLASIC, B. (2011): *Once Upon a Car: The Fall and Resurrection of America's Big Three Auto Makers–GM, Ford, and Chrysler*. Harper Collins.

WARREN, K. (2001): *Big Steel: The First Century of the United States Steel Company, 1901-2001*. University of Pittsburgh Press.

YOON, C. (2012): "The Decline of the Rust Belt: A Dynamic Spatial Equilibrium Analysis," Unpublished Manuscript, University of Pennsylvania.

Appendix

Proof of Proposition 1

The Rust Belt producers' first order condition for optimal investment is

$$(1-\beta)IPz/4 = C'(x_R(i)).$$

The Sun Belt producers' first order condition for investment depends on whether it limit prices the competitive fringe or sets a standard monopolist markup in equilibrium. In the former case, the first order condition is

$$IPz(1+x_S(i))^{-2} = C'(x_S(i)),$$

and in the latter case it is

$$IPz/4 = C'(x_R(i)).$$

Assuming first that parameters are such that both producer types set a monopolist markup in equilibrium, one can combine the two relevant first order conditions to get (16). Since $\beta > 0$, and since $C(\cdot)$ is strictly convex by assumption, it follows that $x_R < x_S$.

If on the other hand, parameters are such that the Rust Belt producer sets a monopolist markup and the Sun Belt producers limit price the fringe, one can combine the two first order conditions to get equation (17). One can also show that this case implies that $x_S < 1$. Since this is true, and since $\beta > 0$ and $C(\cdot)$ is convex, then $x_R < x_S$. ■

Proof of Proposition 2

Combining the first order and envelope conditions for the producers in each region, we can characterize the optimal investment decisions by the following two equations:

$$\begin{aligned}(1+x_S)^{-2}\left[\mu z_R^{\sigma-1}(1+x_R)^{-1}+(1-\mu)z_S^{\sigma-1}(1+\tilde{x}_S)^{-1}\right]^{-1}\left[1+\delta(\sigma-1)x_S\right] \\ = x_S^{\gamma-1}\left[\mu z_R^{\sigma-1}+(1-\mu)z_S^{\sigma-1}\right]^{-1}\left[\gamma+\delta(\sigma-1)x_S\right] \qquad (26)\\ (1+x_R)^{-2}\left[\mu z_R^{\sigma-1}(1+\tilde{x}_R)^{-1}+(1-\mu)z_S^{\sigma-1}(1+x_S)^{-1}\right]^{-1}\left[1+\delta(\sigma-1)x_R\right] \\ = x_R^{\gamma-1}\left[\mu z_R^{\sigma-1}+(1-\mu)z_S^{\sigma-1}\right]^{-1}\left[\gamma+\delta(\sigma-1)x_R\right] \qquad (27)\end{aligned}$$

After imposing symmetric technology choices within the Sun Belt and Rust Belt – that is, $x_R = \tilde{x}_R$ and $x_S = \tilde{x}_S$ – we can show that producers in different industries choose identical technology

investments, regardless of the productivities. To see this, divide (26) by (27) to get

$$\frac{(1+x_S)^{-2}}{(1+x_R)^{-2}} = \frac{x_S^{\gamma-1}}{x_R^{\gamma-1}},$$

which is satisfied only when $x_R = x_S \equiv x$. To show that x is strictly positive, claim that $x = 0$ and evaluate (26). The left-hand side is positive, while the right-hand side is zero. Thus, it must be the case that $x > 0$. This proves part (i).

Regarding part (ii), that output and consumption grow at a constant rate of $1+x$, this follows directly from part (i) and from the definition of the production function, (19). Regarding part (iii), that employment and output shares are constant from one period to the next, we show that this follows from the demand function for an individual producer, (6) and (9). From these, and from the production functions, one can show that

$$\frac{\ell_R}{\ell_S} = \frac{z_R^{\sigma-1}}{z_S^{\sigma-1}},$$

which in turn implies that

$$\frac{\ell'_R}{\ell'_S} = \frac{z_R^{\sigma-1}(1+x)^{\sigma-1}}{z_S^{\sigma-1}(1+x)^{\sigma-1}} = \frac{\ell_R}{\ell_S}.$$

Hence the share of employment in the Rust Belt and Sun Belt stays constant from one period to the next. From the production functions, it follows that the share of output stays constant as well.

To prove part (iv) we rely on the restriction $\mathrm{d}\left(\frac{\tilde{z}_S}{\tilde{z}_R}\right) = 0$ that defines the balanced growth path of our model. To show that the optimal investment x is identical along that path and in the static equilibrium with $\beta = 0$ we only need to establish that the envelope condition satisfies $\frac{\mathrm{d}V_j(Z_j;0,0)}{\mathrm{d}z_j} z_j = 0$, where $j \in \{R,S\}$.

Recall that in any equilibrium we have $z_j = \tilde{z}_j$ and hence $\mathrm{d}z_j = \mathrm{d}\tilde{z}_j$. Together with $\mathrm{d}\left(\frac{\tilde{z}_i}{\tilde{z}_j}\right) = 0$ this implies

$$\mathrm{d}\tilde{z}_i = \mathrm{d}z_j \frac{\tilde{z}_i}{\tilde{z}_j}. \tag{28}$$

The period return is given by

$$\tilde{\pi}_j(Z_j, X_j, 0; 0) - C(x_j, Z_j), \text{ for } j \in \{R,S\} \tag{29}$$

It is straightforward to show that the envelope condition is the differential of (29) multiplied by z_j.

After substituting (28) into the differential and some simple algebra we obtain

$$\frac{\mathrm{d}\tilde{\pi}_i(Z_i,X_i,0;0)}{\mathrm{d}z_i}z_i = \frac{\partial\tilde{\pi}_i(Z_i,X_i,0;0)}{\partial z_i}z_i + \frac{\partial\tilde{\pi}_i(Z_i,X_i,0;0)}{\partial\tilde{z}_i}z_i + \frac{\partial\tilde{\pi}_i(Z_i,X_i,0;0)}{\partial\tilde{z}_j}\tilde{z}_j \tag{30}$$

Knowing that on the balanced growth path $x_i = x_j = x$ one can show that

$$\tilde{\pi}_i(Z_i,X,0;0) = (1+x)\left[\lambda\tilde{z}_R^{\sigma-1} + (1-\lambda)\tilde{z}_S^{\sigma-1}\right]^{-1} z_i^{\sigma-1}\left[\phi^{-1} - (1+x)^{-1}\right] \tag{31}$$

Once we take the three partial derivatives and rearrange

$$\begin{aligned}\frac{\mathrm{d}\tilde{\pi}_i(Z_i,X,0;0)}{\mathrm{d}z_i}z_i =& (\sigma-1)(1+x)\left[\lambda\tilde{z}_R^{\sigma-1} + (1-\lambda)\tilde{z}_S^{\sigma-1}\right]^{-1} z_i^{\sigma-1}\left[\phi^{-1} - (1+x)^{-1}\right] \\ & - (\sigma-1)(1+x)\left[\lambda\tilde{z}_R^{\sigma-1} + (1-\lambda)\tilde{z}_S^{\sigma-1}\right]^{-1} z_i^{\sigma-1}\left[\phi^{-1} - (1+x)^{-1}\right] \\ =& 0\end{aligned} \tag{32}$$

Similarly,

$$\begin{aligned}\frac{\mathrm{d}C(x,Z_i)}{\mathrm{d}z_i}z_i =& \frac{\partial C(x,Z_i)}{\partial z_i}z_i + \frac{\partial C(x,Z_i)}{\partial\tilde{z}_i}z_i + \frac{\partial C(x,Z_i)}{\partial\tilde{z}_j}\tilde{z}_j \\ =& \bar{c}x^{\gamma}z_i^{\sigma-1}(\sigma-1)\left\{\left[\lambda\tilde{z}_R^{\sigma-1} + (1-\lambda)\tilde{z}_S^{\sigma-1}\right]^{-1} - \left[\lambda\tilde{z}_R^{\sigma-1} + (1-\lambda)\tilde{z}_S^{\sigma-1}\right]^{-1}\right\} \\ =& 0\end{aligned} \tag{33}$$

We conclude that $\frac{\mathrm{d}V_i(Z_i;0,0)}{\mathrm{d}z_i}z_i = 0$. ■

Table A.1: Correlates of MSA Wage & Employment Growth, 1950-2000

	Correlation Coefficient	
Measure	Wage Growth	Employment Growth
Average Wage in 1950 (Full-time Males)	-0.59***	-0.33***
Average Wage in 1950 (Males)	-0.65***	-0.32***
Average Wage in 1950 (All)	-0.65***	-0.27***
Wage Premium in 1950 (Full-time Males)	-0.60***	-0.44***
Wage Premium in 1950 (Males)	-0.63***	-0.45***
Wage Premium in 1950 (All)	-0.66***	-0.38***

The correlation coefficients are calculated across Metropolitan Statistical Areas (MSA) that have a population of at least 100,000. The sample includes all private sector wage earners with a positive wage, and the sample is restricted in each row as described in parenthesis. The Average Wage in 1950 is computed as the average hourly wage across individuals in the MSA, defined as labor income in the previous year divided by hours worked in the previous year. The Wage Premium in 1950 is computed as the MSA fixed effect from an individual-level regression of log wages on years of schooling, a quartic polynomial in potential experience and MSA fixed effects. *** significant at 1%

Table A.2: Vehicles Produced per Worker, United States and Japan

Firm	1960	1970	1983
General Motors	8	8	11
Ford	14	12	15
Chrysler	11	11	16
Nissan	12	30	42
Toyota	15	38	58

Source: Adams and Brock (1995), Table 3-5, page 82. Production for General Motors and Chrysler are worldwide. Production for Ford is only within the United States.

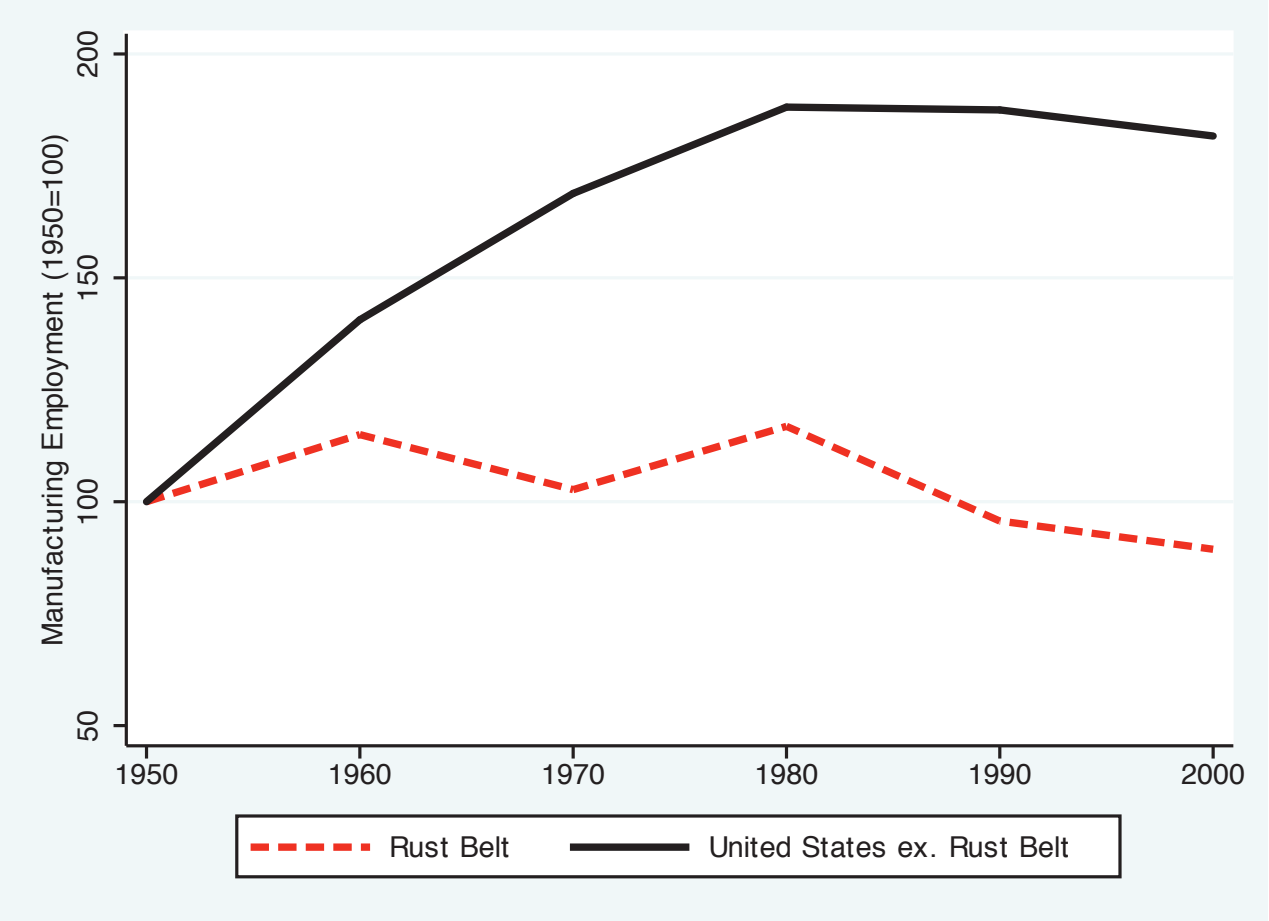


Figure A.1: Manufacturing Employment in Rust Belt and Rest of United States

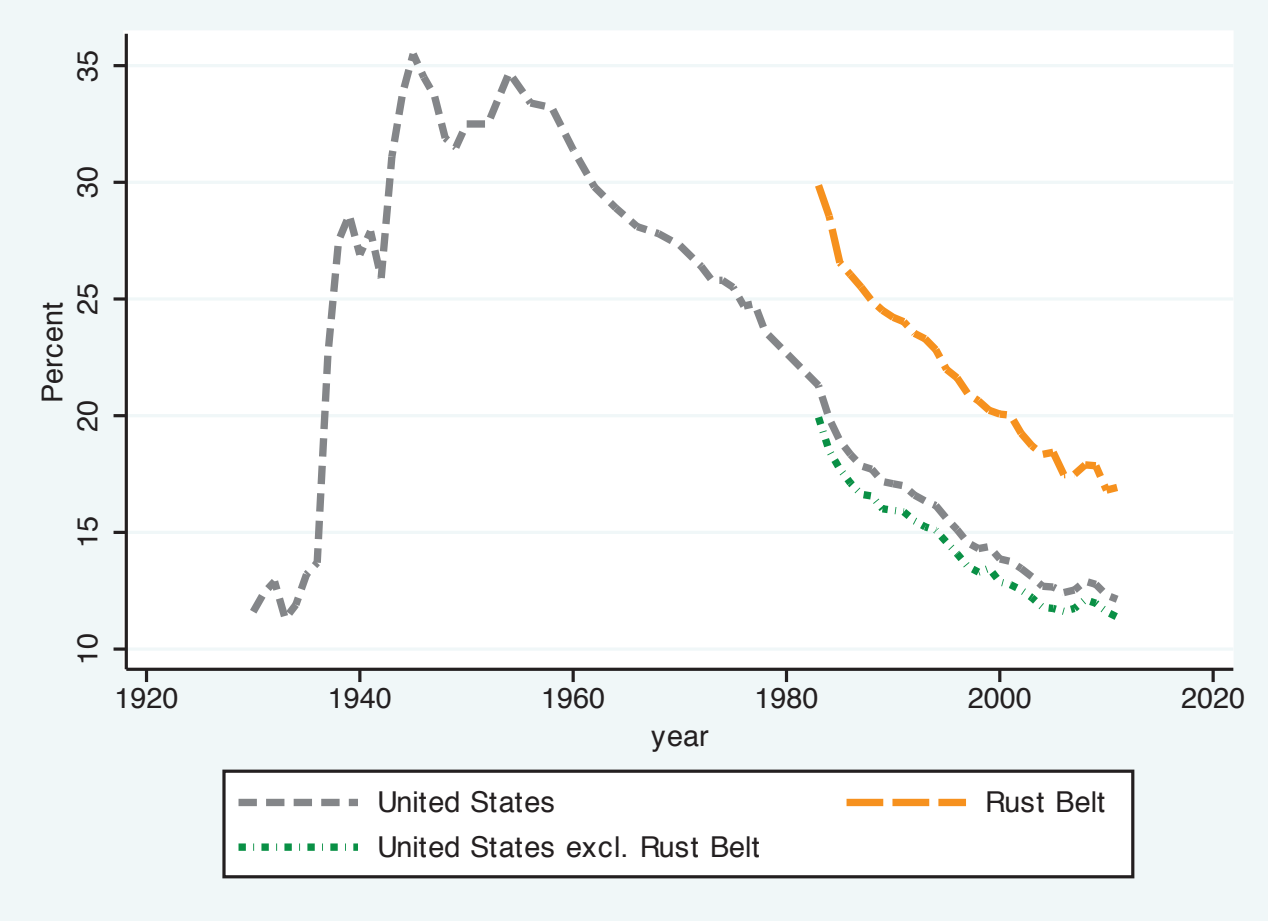


Figure A.2: Unionization Rate in the United States and by Region

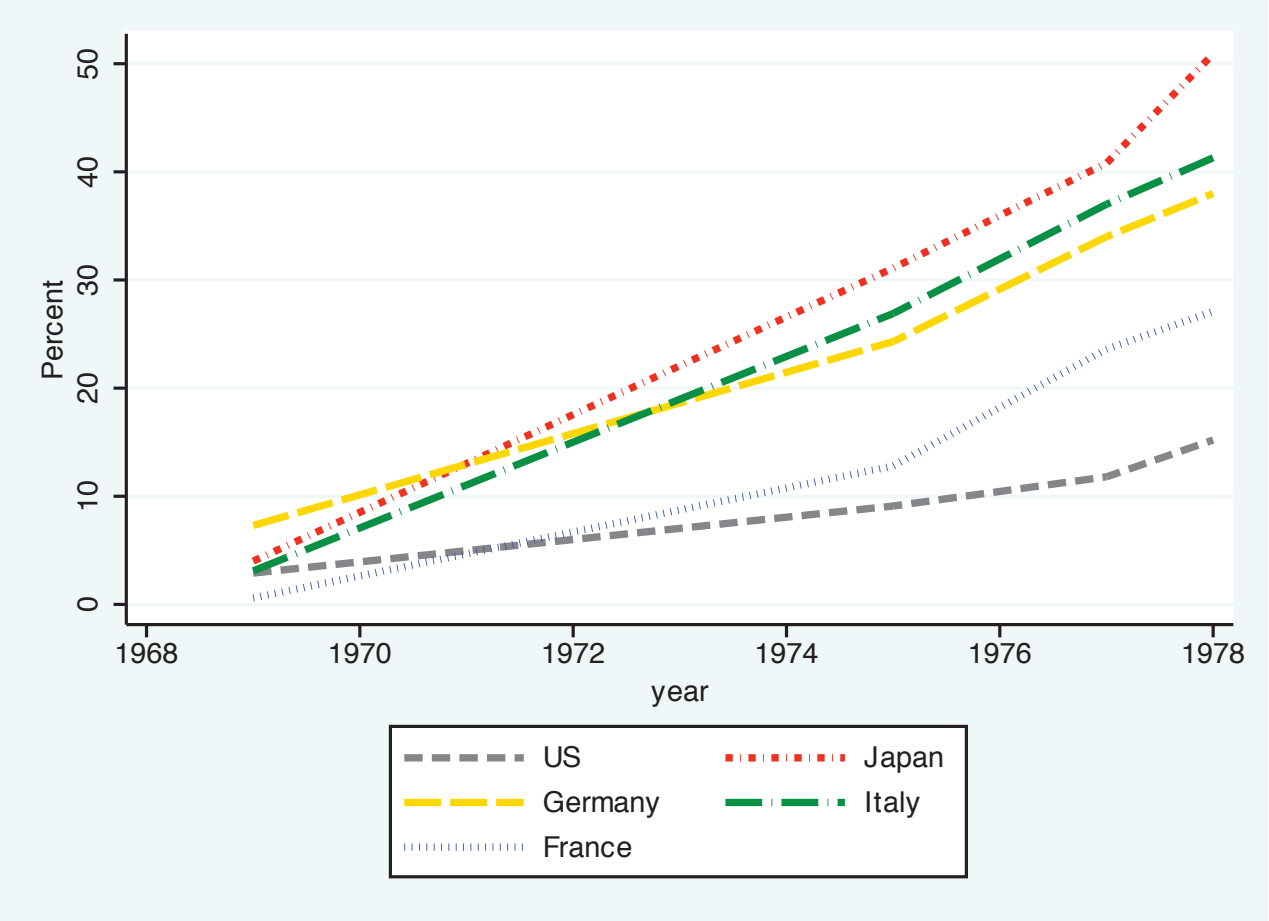


Figure A.3: Fraction of Steel Made Using Continuous Casting Process