Competitive Pressure and the Decline of the Rust Belt

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January 24, 2017

Abstract

No region of the United States fared worse over the postwar period than the "Rust Belt," the heavy manufacturing region bordering the Great Lakes. This paper hypothesizes that the Rust Belt declined in large part due to a lack of competitive pressure. We formalize this thesis in a two-region dynamic general equilibrium model, in which non-competitive labor markets in the Rust Belt lead to a hold-up problem which reduces investment and leads employment to move from the Rust Belt to the rest of the country. Quantitatively, the model accounts for much of the large secular decline in the Rust Belt's employment share before the 1980s, and its relative stabilization since then, as competitive pressure increased. We also provide evidence from the cross-section of U.S. cities and industries that regions and sectors with less competitive labor markets had larger employment declines. An alternative hypothesis, based on a rise in imports, is inconsistent with the timing of the Rust Belt's decline.

Email: simeon.alder.1@nd.edu, lagakos@ucsd.edu, ohanian@econ.ucla.edu. A previous version of this paper circulated under the title "The Decline of the U.S. Rust Belt: A Macroeconomic Analysis." We thank Ufuk Akcigit, David Autor, Marco Bassetto, Jeffrey Campbell, Jesus Fernandez-Villaverde, Pablo Fajgelbaum, Jeremy Greenwood, Berthold Herrendorf, Tom Holmes, Alejandro Justiniano, Joe Kaboski, Thomas Klier, Michael Peters, Andrea Pozzi, Ed Prescott, Andres Rodriguez-Clare, Leena Rudanko, Jim Schmitz, Todd Schoellman, Marcelo Veracierto, Fabrizio Zilibotti and seminar participants at Arizona State, Autonoma de Barcelona, Berkeley, Brown, British Columbia, the Bank of Chile, Chicago Booth, Columbia, the Federal Reserve Banks of Atlanta, Chicago, Minneapolis, St. Louis and Richmond, Frankfurt, LSE, Montreal, Notre Dame, NYU, Ohio State, Pennsylvania, Temple, UCLA, UCSB, UCSD, USC, Wharton, Yale, Zurich, the NBER Macroeconomics across Time and Space 2014 meeting, the NBER Summer Institute 2013 (EFBGZ and PRMP), the GSE Summer Forum, the 2013 Midwest Macro meeting, the February 2013 NBER EFG meeting, the 2012 Einaudi Roma Macro Junior conference, and the 2012 SED meeting (Cyprus) for helpful comments. We thank Andrew Cole, Alex Hartman, Patrick Kiernan, Patrick Orr, Samin Peirovi, Billy Smith and especially Caleb Johnson and Glenn Farley for excellent research assistance. All potential errors are ours.

1. Introduction

No region of the United States fared worse over the postwar period than the "Rust Belt," the heavy manufacturing region largely bordering the Great Lakes. From 1950 to 2000, the Rust Belt's share of U.S. manufacturing employment fell from more than one-half to around one-third, and its share of aggregate employment dropped by a similar magnitude.[1]

This paper develops and quantitatively analyzes a theory of the Rust Belt's economic decline based on lack of competitive pressure in Rust Belt labor and product markets. This theory is motivated by four observations that we document in detail below. One is that Rust Belt wages – even after controlling for observables – were about 12 percent higher than the rest of the country between 1950-80. A second is that productivity growth was relatively low in the Rust Belt between 1950-1980. A third is that Rust Belt labor relations between unions and management were highly conflicted between 1950-1980, featuring frequent strikes and strike threats, and worker slowdowns that dominated Rust Belt collective bargaining agreements. The fourth observation is that all of these patterns shifted significantly after 1980; the Rust Belt wage premium declined significantly, Rust Belt productivity growth accelerated, the Rust Belt's employment share stabilized, and Rust Belt labor relations became much less conflicted and more cooperative.

We develop a general equilibrium model of the U.S. economy with two regions, the Rust Belt and the Rest-of-the-Country (ROC) to assess how the lack of competitive pressure affected Rust Belt economic activity between 1950-2000. The two regions differ in the extent of product market and labor market competition. Labor markets in the Rust Belt region are tailored to capture the highly conflicted labor relations of Rust Belt unions and firms. To integrate the importance of the strike threat into the analysis, the model's Rust Belt labor market features a hold-up problem in which Rust Belt unions and firms bargain over industry rents after Rust Belt firms have made investments, and in which Rust Belt unions use the strike threat to capture some of the returns from investment. This hold-up problem acts as a tax on investment, and provides Rust Belt union members with higher wages than in the rest of the country. Moreover, this de facto investment tax leads to lover investment by Rust Belt firms relative to ROC firms that operate in competitive labor markets. Lower investment in the Rust Belt leads to relatively low productivity growth, and a shift in labor from the Rust Belt to the ROC.

In product markets, the model captures the role of competition from abroad using simple Ricardian trade forces. The final consumption good is produced using an Armington aggregator over foreign and domestic varieties, which are imperfect substitutes. International trade is subject to iceberg

[1] We define the Rust Belt to be the states of Illinois, Indiana, Michigan, New York, Ohio, Pennsylvania, West Virginia and Wisconsin. We discuss our data in detail in Section 3.

trade costs, which may change over time. We assume two layers of aggregation over foreign and domestic varieties following Atkeson and Burstein (2008) and Edmond, Midrigan, and Xu (2015), and allow the foreign Rust Belt varieties to be produced with a different productivity level than other foreign varieties. Thus, if the foreign sector has a comparative advantage in varieties that the Rust Belt produces, then a fall in trade costs will lower the Rust Belt's share of output and employment.

The focus of our model on lack of competitive pressure builds on a growing literature that connects lack of competition with low productivity growth (see e.g. Acemoglu, Akcigit, Bloom, and Kerr, 2013; Aghion, Bloom, Blundell, Griffith, and Howitt, 2005; Schmitz, 2005; Holmes and Schmitz, 2010; Syverson, 2011), though our emphasis on hold-up has not received much prior attention in this literature. Our model's integration of depressed productivity growth with regional decline is related to models of structural change, in which differential employment dynamics and differential sectoral productivity growth go hand-in-hand (see e.g. Ngai and Pissarides, 2007; Buera and Kaboski, 2009; Herrendorf, Rogerson, and Valentinyi, 2014).

Regional employment shares in the model evolve endogenously and are driven by the extent of competition in labor markets, captured by union bargaining power, and from abroad, capturing using iceberg trade costs. Since goods are gross substitutes in production, regional employment shares are determined by relative productivity levels and trade costs with foreign producers. There are two channels by which the Rust Belt's employment share can decline in the model. The first is that if the Rust Belt producers invest less than those in the rest of the country, then the relative productivity level of the Rust Belt falls, their relative price increases, and the employment share of the Rust Belt falls. The second is that if trade costs fall, and if the United States has a comparative disadvantage in Rust Belt goods, then the Rust Belt's share of employment will also fall as imports rise relatively more for Rust Belt goods.

We use the model to quantify how much of the Rust Belt's employment share decline can be accounted for by the two channels of competition. To do so, we discipline the extent of union power in labor markets by the Rust Belt wage premia. We also provide direct evidence that these wage premia likely reflected rents, rather than a higher cost of living or higher unmeasured worker ability. We govern the extent of foreign competition by the import shares in the United States as a whole and in the automobile and steel industries, which were concentrated in the Rust Belt. We show that import shares were low until around 1980, and then increased substantially afterward, particularly in automobiles and steel.

We then calculate the equilibrium of the model from 1950 through 2000, in which investment, productivity growth, and employment shares endogenously evolve in the two regions. The model predicts a steady secular decline in the Rust Belt's employment share until 1980, a one-time drop in 1980, and a modest decline afterwards. The model's overall decline is 9.8 percentage points, compared to 18 percent points in the data, and hence the model accounts for around 54 percent of the Rust Belt's decline. The model is also consistent with the timing of the Rust Belt's decline, which mostly comes before 1980, has a one-time drop around 1980, and then is largely flat afterwards. Finally, the model is consistent with the Rust Belt's productivity growth. We document labor productivity growth was lower on average in the Rust Belt's main industries than in the other industries before the 1980s, and that productivity growth rose dramatically in many Rust Belt industries since then. This is exactly what our model predicts.

To decompose the importance of the theory we conduct two counterfactual experiments using the model. First, we assume trade costs were constant over this period, so that only the labor-markets channel leads to a Rust Belt decline. Second, we assume labor market frictions were constant over the period, so that only the imports-competition channel operates. We find that it in this latter case, the timing of the Rust Belt's decline is inconsistent with the data, with almost all of the decline happing counterfactually after 1980. In contrast in the counterfactual with only the labor-markets competition channel operating, the timing of the decline is largely in line with the data, with the bulk of the decline coming pre 1980. It also generates a larger decline, though not as large as in the data, of around 7.2 percentage points, or 40 percent of the observed decline.

We conclude by presenting additional micro evidence supporting the theory's mechanism and predictions. First, we show that across U.S. industries, those industries with the highest unionization-rate differentials between the Rust Belt and rest of country had the largest differentials in employment declines since 1950. Second, we show that across U.S. Metropolitan Statistical Areas (MSAs), those MSAs that paid the highest wage premia in 1950 tended to have the lowest employment growth since 1950. To the extent that higher unionization rates or wage premia reflect non-competitive labor markets, these findings provide further disaggregated evidence that a lack of competitive pressure in labor markets played a role in regional employment changes. Finally, we present historical evidence that technology adoption rates in Rust Belt industries lagged behind their foreign counterparts and other domestic industries. This supports the view that investment in the Rust Belt was low by the industry standards of the time.

The paper is organized as follows. Section 2 places the paper in the context of the related literature. Section 3 documents four facts which characterize the Rust Belt's decline. Section 4 presents evidence that competitive pressure was low in the Rust Belt's output and labor markets over the postwar period. Section 5 presents the model economy. Section 6 presents the quantitative analysis. Section 7 presents additional supporting evidence and Section 8 concludes.

2. Related Literature

Few prior papers have attempted to explain the root causes of the Rust Belt's decline. The only other theory of which we are aware is that of Yoon (Forthcoming), who argues, in contrast to our work, that the Rust Belt's decline was due in large part to rapid technological change in manufacturing. Glaeser and Ponzetto (2007) theorize that the decline in transportation costs over the postwar period may have caused the declines of U.S. regions whose industries depend on being close to their customers, of which the Rust Belt is arguably a good example. Our paper also differs from the work of Feyrer, Sacerdote, and Stern (2007) and Kahn (1999), who study labor-market and environmental consequences of the Rust Belt's decline, respectively, but do not attempt to explain the underlying causes of the decline. Our model is consistent with the findings of Blanchard and Katz (1992), who argue that employment losses sustained by the Rust Belt led to population outflows rather than persistent increases in unemployment rates.

Our paper relates to other theories of changes in the spatial distribution of U.S. economic activity more generally. Desmet and Rossi-Hansberg (2009) show that U.S. countries with the lowest initial population density had the highest manufacturing employment growth rates on average since 1970. They reconcile these facts in a model where mature industries disperse across space as knowledge spillovers decline in importance. Duranton and Puga (2009) document that, since 1950, U.S. cities have increasingly specialized in management and less in production, which they explain using fall costs of communication and management across space. It is an open question how well these these theories explain the movement of manufacturing from Rust Belt states to other states, as opposed to from denser areas to less-dense areas within the Rust Belt.

By focusing on competition, our paper builds on a recent and growing literature linking competition and productivity. Schmitz (2005) shows that in the wake of a large increase in competitive pressure in the 1980s, the U.S. iron ore industry roughly doubled its labor productivity. Similarly, Bloom, Draca, and Van Reenen (2016) present evidence that European firms most exposed to trade from China innovated and raised productivity more than other firms. Pavcnik (2002) documents that after the 1980s trade liberalization in Chile, producers facing new import competition saw large gains in productivity. Cole, Ohanian, Riascos, and Schmitz Jr. (2005) show that productivity growth, and in some cases productivity levels, declined substantially in a number of Latin American countries when they received protection from competition, and that productivity rebounded once protection ended. Holmes and Schmitz (2010) review a number of other studies at the industry level that document the impact of competition on productivity. Our work also builds on several recent endogenous growth models where innovation depends on the extent of the competition in output markets, in particular Acemoglu and Akcigit (2011), Aghion, Bloom, Blundell, Griffith, and Howitt (2005), Aghion, Akcigit, and Howitt (2014) and Peters (2013), though we more heavily emphasize the hold-up problem in labor markets than the previous literature.[2]

Our paper 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.[3] Our work also resembles that of Taschereau-Dumouchel (2015), 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 (2015), who argues that a union may rationally prefer inefficient production so long as competition is sufficiently weak.[4]

Finally, our paper relates to those studying the effects of a rise in import penetration on U.S. regions and industries. Recently, Autor, Dorn, and Hanson (2013a) and Autor, Dorn, Hanson, and Song (2014) have documented that workers in U.S. industries that are more exposed to imports from China since 1990 have experienced substantial negative wage growth and labor market outcomes. Though imports from China were only 2 percent in 1990, and negligible before that, and thus imports from China are quite unlikely to have played an important role in the Rust Belt's decline from 1950 to 1990. Furthermore, most of the affected regions were located outside the Rust Belt (see Autor, Dorn, and Hanson, 2013b, Figure 1B). For the earlier period of 1977 to 1987, Revenga (1992) estimates a negative impact of import penetration on U.S. manufacturing, which is consistent with our model's predicted decline in the Rust Belt's share of manufacturing employment in the early 1980s, though again, this is after the bulk of the Rust Belt's employment share decline.[5]

[2]Our model also relates to those of Parente and Prescott (1999) and Herrendorf and Teixeira (2011), where monopoly rights reduce productivity by encouraging incumbent producers to block new technologies, and that of Holmes, Levine, and Schmitz (2012), in which firms with market power have less incentive to innovate because technological adoption temporarily disrupts production.

[3]Bradley, Kim, and Tian (Forthcoming) use a regression discontinuity approach to examine the effect of unionization decisions by U.S. workers on innovation from 1977 to 2010, finding a significant negative effect on patent quantity and quality three years after unionization. This is consistent with our hold-up theory, though largely from a later time period.

[4]While our model takes the extent of competition in labor markets 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 (2014) 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 well as other papers in the literature, such as that of Borjas and Ramey (1995) and that of Taschereau-Dumouchel (2015), is the link between inequality and unionization, which is absent from the current paper.

[5]Most of these import increases of the 1980s were from advanced economies like Japan. Bernard, Jensen, and Schott (2006) estimate negative effects on U.S. manufacturing employment of import penetration from low-wage countries from 1977 to 1992, though virtually none of these were in Rust Belt industries like fabricated metals, transportation equipment or industrial machinery.

3. Decline of the Rust Belt: The Facts

In this section we document a set of facts characterizing the Rust Belt's decline. We begin with the decline itself, by showing that the Rust Belt's share of aggregate and manufacturing employment declined secularly over the postwar period. We then document that wages in the Rust Belt were higher than in the rest of the country from even after controlling for observables, that labor productivity growth in industries located predominantly in the Rust Belt was lower than average, and that all these empirical patterns changed significantly in the 1980s.

Definition of the Rust Belt

We define the Rust Belt as the states of Illinois, Indiana, Michigan, New York, Ohio, Pennsylvania, West Virginia and Wisconsin. This definition encompasses the heavy manufacturing area bordering the Great Lakes, and is similar to previous uses of the term (see, e.g., Blanchard and Katz (1992), Feyrer, Sacerdote, and Stern (2007) and the references therein). Our main data are the U.S. Censuses of 1950 through 2000, available through the Integrated Public Use Microdata Series (IPUMS). We restrict our sample to private-sector workers who are not primarily self-employed. We also draw on state-level employment data from 1970 and onward from the U.S. Bureau of Economic Analysis (BEA), and BEA state-level value-added and wage data from 1963 onward.

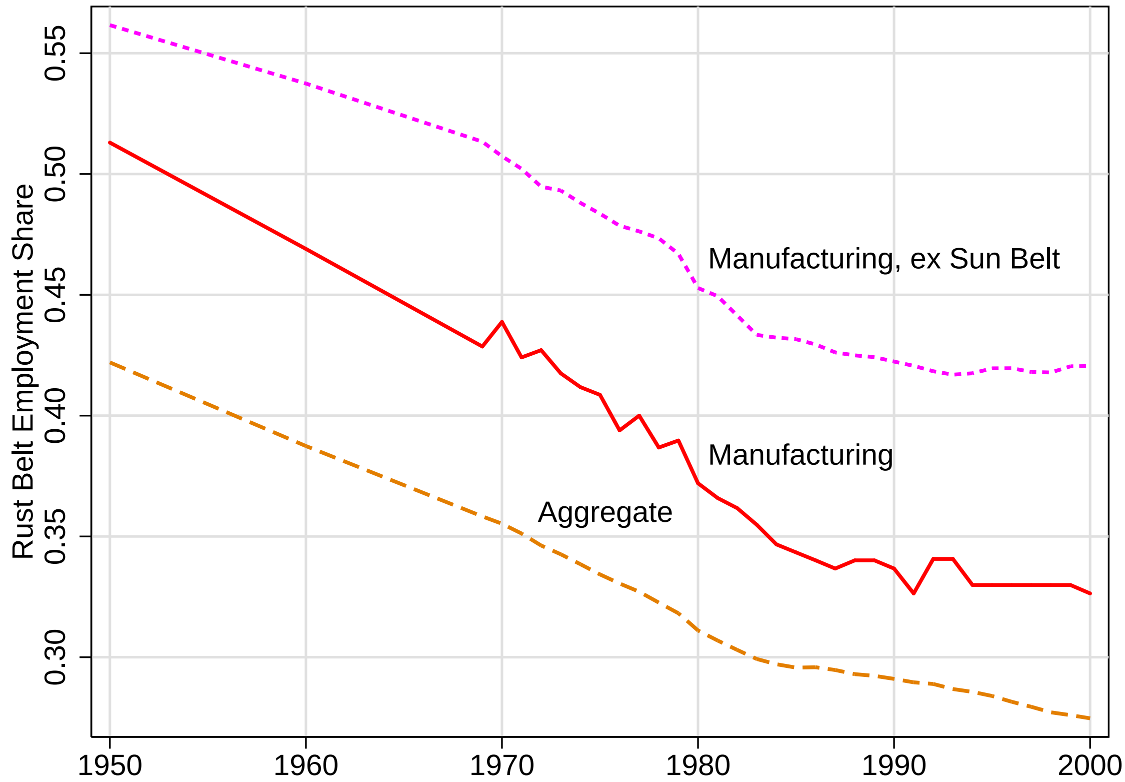
Decline of the Rust Belt's Employment Share

We first show how the Rust Belt's share of employment decreased secularly over the postwar period. Figure 3 plots the Rust Belt's share of employment from 1950 through 2000 by three different metrics. The aggregate employment share of the Rust Belt (solid red) began at 43 percent in 1950, and declined to 27 percent in 2000. The manufacturing share of the Rust Belt (dotted purple) began at 51 percent in 1950 and declined to 34 percent. The aggregate share of employment in states other than the "Sun Belt" states of Arizona, California, Florida, New Mexico and Nevada (Blanchard and Katz, 1992) (dashed orange) was 49 percent in 1950 and 36 percent in 2000. We discuss each of these in turn.[6]

The fact that the Rust Belt's share of manufacturing employment dropped so much indicates that the decline is not just a structural shift out of manufacturing. The dotted purple line in Figure 3 clearly shows that the Rust Belt's share of employment declined even within manufacturing. Thus, even though manufacturing was declining relative to services in the aggregate, employment *within the manufacturing sector* shifted from the Rust Belt to the rest of the country. Furthermore, this pattern holds even within more narrowly defined industries. For example the Rust Belt's share of

[6]The Rust Belt's share of GDP also declined secularly since 1950, from 45 percent down to 27 percent in the aggregate, and from 56 percent down to 32 percent in manufacturing.

Figure 1: The Rust Belt's Employment Share



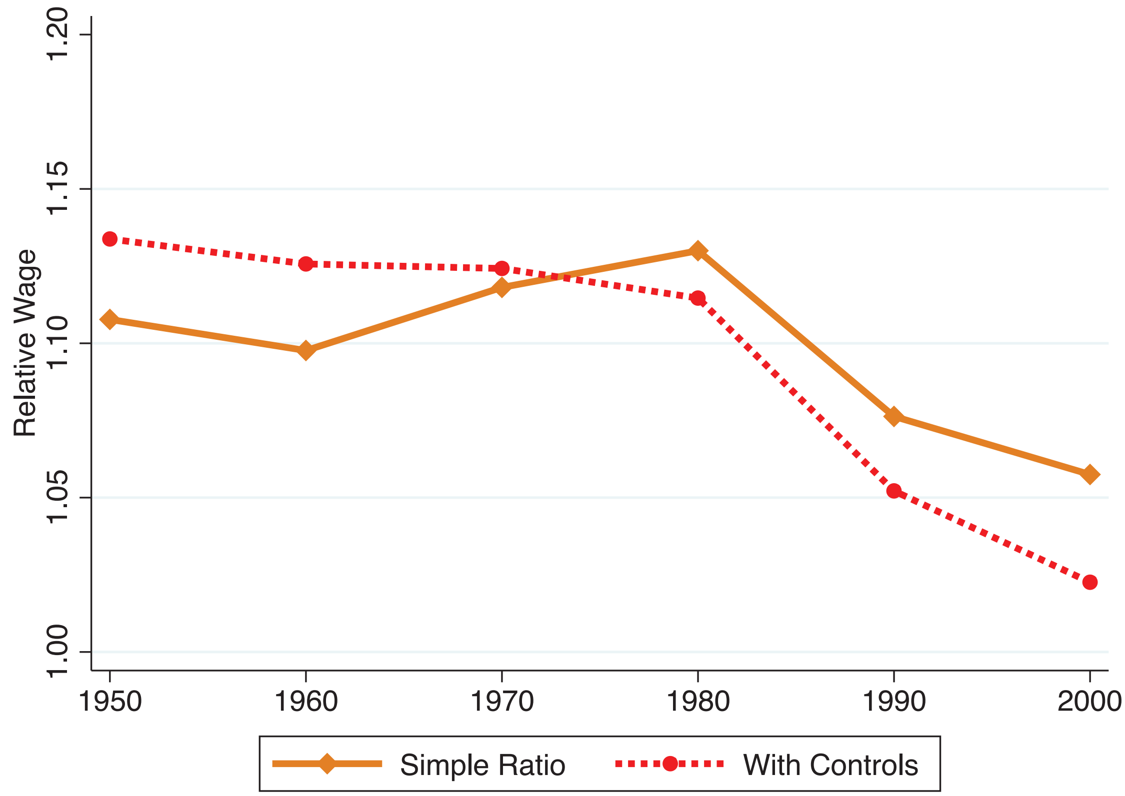
U.S. employment in steel, autos and rubber tire manufacturing fell from 75 percent in 1950 to 55 percent in 2000.

The dashed orange line in Figure 3 shows that the Rust Belt's decline is not accounted for by movements, possibly related to weather, of workers to the "Sun Belt." In contrast, the Rust Belt's employment share declined substantially even after excluding these states. This is consistent with the work of Holmes (1998), who studies U.S. counties within 25 miles of the border between right-to-work states (most of which are outside the Rust Belt) and other states, and finds much faster employment growth in the right-to-work state counties next to the border than in counties right across the state border.[7]

More broadly, no region in the U.S. declined as much as the Rust Belt. Of the seven states with the largest drops in their share of aggregate employment between 1950 and 2000, six are in the Rust Belt. Of the seven states with the sharpest decline in manufacturing employment, five are in the Rust Belt. Finally, taken individually, every single Rust Belt state experienced a substantial fall in

[7] It is also consistent with the findings of Rappaport (2007), who concludes that weather-related migration out of the states in the Rust Belt played only a modest role in their declining population share. Other areas in the midwest, and New England, for example, have similar weather but had much smaller population declines.

Figure 2: Relative Wages of Rust Belt Workers



aggregate and manufacturing employment relative to the rest of the country.

High Wages in the Rust Belt

Next, we we document is that relative wages were higher in the Rust Belt than in the rest of the economy for most of the postwar period. Figure 3 plots two measures of the relative wages earned by manufacturing workers in the Rust Belt. We focus on manufacturing since the mechanisms we emphasize in our theory are particularly salient in this sector (though the patterns hold when we include all workers; see Appendix Table C.1.) The first (solid line) is the ratio of average wages of manufacturing workers in the Rust Belt to average wages of all other U.S. manufacturing workers, where wages are calculated as the ratio of annual labor earnings to annual hours. Clearly, wages in the Rust Belt were considerably higher throughout this period. The wage premium was between 10 percent to 15 percent between 1950 and 1980, and lower, yet still positive, afterwards.

The second measure (dotted line) is the Rust Belt wage premium among manufacturing workers when adding controls for schooling, potential experience, race and sex. Specifically, the line is the coefficient of a Rust Belt dummy variable interacted with the year in a Mincer-type regression. The pattern is similar to that of the first wage measure. The wage premium coefficients are above one for the entire period, hovering around 13 percent between 1950 and 1980, and falling afterwards (though still remaining positive.) Thus, even after controlling for standard observables, manufacturing workers in the Rust Belt earned more than workers in the rest of the country.

One possible interpretation of this wage premium is that the cost of living was higher in the Rust Belt than in other parts of the country. While time series on regional costs of living in the United States do not exist, the BLS did estimate costs of living in a sample of 39 cities in one year, 1966, in the middle of our time period (U.S. Bureau of Labor Statistics, 1967). When comparing the average cost of living in Rust Belt cities to the average for the rest of the country, we find that the difference is small in magnitude, with the Rust Belt cities being at most two percent more expensive. The difference in average cost of living is also statistically insignificant. These data therefore cast substantial doubt on the interpretation of cost-of-living differences explaining the wage premium.[8]

A second possible interpretation is that workers in the Rust Belt were more productive on average, even after controlling for schooling and experience, at least in the period up until the 1980s. As one way of evaluating this possibility, we consider data on wage loss of displaced workers from the Rust Belt compared to the rest of the country. The data are available as part of the Displaced Workers supplement to the Current Population Survey (CPS) of 1986, which asked follow-up questions of each worker that was displaced from a job between 1981 and 1986 (Flood, King, Ruggles, and Warren, 2015). What we find is that Rust Belt workers lost 8 percent of their pre-displacement wages on average after a plant closing, compared to 5 percent for workers in the rest of the country. The difference is statistically significant at the one-percent level. If anything, this points to rents among Rust Belt workers rather than more productive workers there.[9]

Low Productivity Growth in Rust Belt Industries

The next fact we document is that labor productivity growth was lower for much of the postwar period in manufacturing industries prevalent in the Rust Belt. The main challenge we face is that direct measures of productivity growth by region are not available for many industries. Our approach is to focus on measures of productivity growth in a broad set of industries by matching productivity data by industry to census data containing the geographic location of employment for each industry. This allows us to compare productivity growth in the industries most common in

[8] We present our results in more detail in Appendix X.

[9] See Appendix X for more details on our calculations. Our findings are consistent with the industry evidence of Carrington and Zaman (1994), who find the highest wage loss for displaced workers from heavily unionized industries, such as primary metals manufacturing and transport equipment manufacturing. Our findings are also consistent with those of Jacobson, Lalonde, and Sullivan (1993) who study wage losses from displacement among high-tenure manufacturing workers in Pennsylvania, and find that "losses are larger in settings where unions or rent-sharing are likely to be prevalent..."

Table 1: Labor Productivity Growth in Rust Belt Industries

	Annualized Growth Rate, %		
	1958-1985	1985-1997	1958-1997
Blast furnaces, steelworks, mills	0.9	7.6	2.8
Engines and turbines	2.3	2.9	2.5
Iron and steel foundries	1.5	2.3	1.7
Metal forgings and stampings	1.5	2.8	1.9
Metalworking machinery	0.9	3.5	1.6
Motor vehicles and motor vehicle equipment	2.5	3.8	2.9
Photographic equipment and supplies	4.7	5.1	4.9
Railroad locomotives and equipment	1.6	3.1	2.0
Screw machine products	1.2	1.1	1.2
Rust Belt weighted average	2.0	4.2	2.6
Manufacturing weighted average	2.6	3.2	2.8

Note: Rust Belt Industries are defined as industries whose employment shares in the Rust Belt region in 1975 are more than one standard deviation above than the industry mean. Labor Productivity Growth is measured as the growth rate of real value added per worker. Rust Belt weighted average is the employment-weighted average productivity growth rate for Rust Belt industries. Manufacturing weighted average is the employment-weighted average productivity growth across all manufacturing industries. Source: Author's calculations using NBER CES productivity database, U.S. census data from IPUMS, and the BLS.

the Rust Belt to other industries.

To define Rust Belt intensive industries, we match NBER industries (by SIC codes) to those in the IPUMS census data (by census industry codes). In each industry, we then compute the fraction of employment located in the Rust Belt. We define "Rust Belt industries" to be those whose employment share in the Rust Belt is more than one standard deviation above the mean. In practice, this turns out to be a cutoff of at least 68 percent of industry employment located in the Rust Belt.

Table 1 reports productivity growth rates for the Rust Belt industries and their average over time. Productivity growth is measured as the growth in real value added per worker, using industry-level price indices as deflators. The first data column reports productivity growth in each industry, and the Rust Belt weighted average, for the period 1958 to 1985. On average, productivity growth rates were 2.0 percent per year in Rust Belt industries and 2.6 percent in all manufacturing industries. Productivity growth rates in the Rust Belt were much higher between 1985 and 1997 than before, averaging 4.2 percent per year, compared to 3.2 percent for all manufacturing industries. For the whole period, the Rust Belt industries had slightly lower productivity growth (2.6 percent) than all manufacturing industries (2.8 percent).[10]

One potential limitation of the productivity measures of Table 1 is that they do not directly measure productivity by region. However, these productivity measures are consistent with studies that do measure productivity by region directly, using plant-level data. For the steel industry, Collard-Wexler and De Loecker (2015) measure labor productivity growth and TFP growth by two broad types of producers: the vertically integrated mills, most of which were in the Rust Belt, and the minimills, most of which were in the South. They find that for the vertically integrated mills, TFP growth was very low from 1963 to 1982 and, in fact, negative for much of the period. In contrast, they report robust TFP growth post-1982 in the vertically integrated mills. TFP improved by 11 percent from 1982 to 1987 and by 16 percent between 1992 and 1997.

Changes of the 1980s

The three acts described above - the substantial decline in its employment share, its wage premium, and its low productivity growth - changed significantly in the 1980s. Figure 3 shows that the decline in the Rust Belt's employment share slowed after 1985. Specifically, the Rust Belt's share of aggregate employment declined by about 12 percentage points between 1950 and 1985, but declined only 3 percentage points afterwards. Similarly, the Rust Belt's manufacturing employment share declined by about 16 percentage points between 1950 and 1985, but declined by only 2 additional percentage points from 1985 to 2000.

Figure 3 shows the decline in the Rust Belt's wage premium around 1980. The ratio of average wages in the Rust Belt to the rest of the country fell from around 1.13 in 1980 to around 1.07 in 1990 and to 1.06 by 2000. Controlling for education, experience, gender, and race, the Rust Belt wage premium fell from 1.12 until 1980 down to 1.05 in 1990 and to 1.02 by 2000. Appendix Table C.1 shows that the Rust Belt wage premium falls after 1980 when including all workers, when restricting to full time workers, and when including dummies for more detailed race and educational attainment categories.

As described above, Table 1 shows the Rust Belt productivity pickup after 1985. In the largest single Rust Belt industry, blast furnaces & steel mills, productivity growth averaged just 0.9 percent per year before 1985 but rose substantially to an average of 7.6 percent per year after 1985. Large productivity gains after 1985 are also present in all but one of the nine industries most common in the Rust Belt. Their average growth rate was 2.0 percent year from 1958 to 1985, but rose 4.2 percent per year after 1985. We also find that investment rates increased substantially in most Rust

[10]In Appendix Table C.2 we show that our results hold for a broader definition of Rust Belt industries. We also find lower productivity growth rates in Rust Belt industries between 1958 to 1985 when using double-deflated value added per worker or TFP as our measure of productivity. A detailed description of the NBER CES data, and the data themselves, are available here: http://www.nber.org/nberces/.

Belt industries in the 1980s, rising from an average of 4.8 percent to 7.7 percent per year. Appendix Table C.2 shows that productivity increases occurred, on average, under a broader definition of Rust Belt industries.

4. Competition in the Rust Belt: Historical Evidence

In this section, we provide historical evidence that labor markets in the Rust Belt were highly non-competitive for most of the post-war period. We first provide evidence that Rust Belt industries were characterized by conflict between management and labor starting from the 1930s, when the unions were formed, and continuing throughout the post-war period. This conflict resulted in unions using the threat of strikes to extract higher surplus from firms. We then discuss how union-management relationships shifted became more efficient and cooperative around the 1980s, and that strike activity declined substantially around then. Finally, we cite evidence that the threat of strikes, and conflicted labor relations more broadly, reduced investment and productivity growth.

4.1. Post-World War II Labor Conflict in the Rust Belt

The threat of strikes, and conflict between unions and management more generally, were a central feature of the main Rust Belt industries in the post-war period. The conflict began with the violent union organizations of these industries in the late 1930s. Prior to that time, Rust Belt firms had prevented a number of union organization attempts. Union organization ultimately succeeded in the late 1930s through the use of the sit-down strike, in which strikers forcibly occupied factories to stop production. This strike method was tacitly permitted by the National Labor Relations Act of 1935 before being ruled unconstitutional by the Supreme Court in 1939, and significantly facilitated union organization during the late 1930s (Kennedy, 1999; Millis and Brown, 1950).[11]

By the early 1940s, all of the major auto, steel and rubber producers were unionized, and many studies describe how these organizational strikes created deep distrust and resentment between management and labor (see Clark (1982), Barnard (2004) and Strohmeyer (1986)). As an example of the level of the conflict that existed between management and labor, Barnard (2004) describes that there were 170 separate strikes at GM in just the first four months following their union organization in 1937. During World War II, labor relations were largely managed by the government as most major unions agreed to President Roosevelt's no-strike pledge, and the National War Labor Board limited wage increases to cost of living increases (see Cole and Ohanian (2004) and the

[11] General Motors was among the first Rust Belt firms violently organized by the sit-down strike. Striking workers forcibly shut down production at some G.M. auto body plants, which led G.M. to recognize the U.A.W. in 1937 as their worker's sole bargaining representative. The G.M. sit-down strikes led to many other violent organization strikes. This included the deaths of ten strikers at a sit-down, organizational strike at Republic Steel (Barnard, 2004). The threat of a sit down strike led U.S. Steel to recognize the union precursor of The United Steel Workers in mid-1937.

references therein).

Conflict and strikes emerged immediately after the war, as unions sought large wage increases following wartime wage controls. This conflict is viewed widely as reflecting the violent union organizations of the 1930s. For example, a 1982 National Academy of Sciences project on the U.S. auto industry argues that the violent union organizations and sit-down strikes of the late 1930s defined an "adversarial and bitter relationship between labor and management" (Clark, 1982). Barnard (2004), Katz (1985), Kochan, Katz, and McKersie (1994), Kuhn (1961), Serrin (1973) and Strohmeyer (1986) also describe how the organization conflicts of the 1930s and 1940s evolved into chronically conflicted relations in which the strike threat dominated Rust Belt labor negotiations after World War II. Moreover, Lodge (1986), Nelson (1996) and Lam, Norsworthy, and Zabala (1991) describe how this conflict was much more prevalent in U.S. Rust Belt industries, compared to union-management relations in other U.S. industries, or in union-management relations in other countries.

There were major Rust Belt strikes after World War II, including very large strikes in the steel and auto industries (see Richter (2003)). The BLS called this period "the most concentrated period of labor-management strife in the country's history" (see Seidman (1953), pp. 78-79). Rust Belt industries tried to deal with the chronic threat of strikes by adopting five-year bargaining agreements that in principle would maintain peaceful relations over the contract term, rather than expose industry to the possibility of more frequent strikes. The first five year contract was between GM and the U.A.W in 1950, and is known as the "Treaty of Detroit," as its goal was to create peace between labor and management (see Barnard (2004)). This five-year approach was adopted by other auto firms, and by some firms in other Rust Belt industries.

However, conflict re-emerged following the expiration of these collective bargaining agreements. There were several three-year labor agreements in the steel industry, and steel strikes occurred roughly every three years between 1946 and 1959. The steel strikes of 1952 and 1959 led Presidents Truman and Eisenhower to intervene, as Truman tried to nationalize the steel industry in 1952, and Eisenhower tried to force a settlement between union and management in 1959 in a strike involving 500,000 workers. Strikes led Rust Belt industries to attempt to resolve this conflict in a variety of ways. One approach was to try to escape the conflict by moving some industry operations outside of the Rust Belt. Nelson (1996) discusses how the auto industry developed a relocation plan that was known as the "Southern Strategy" in the 1960s and 1970s. This involved moving operations to states where unions were less prevalent. However, this approach did not achieve what management had hoped. Nelson describes that "the UAW was able to respond (to the Southern Strategy) by maintaining virtually 100 percent organization of production workers in all production facilities" (see Nelson (1996), p 165).

Another approach to escape conflict was to substitute capital for labor. The auto industry initiated this process in the 1950s, when Ford introduced automation technologies in some plants (Meyer, 2004). Serrin (1973) describes how this process accelerated in the early 1970s following the 1970 G.M. strike, which involved roughly 500,000 workers. However, this approach did not work as management intended, as attempts to substitute capital for labor led the UAW to specify work rules and job classifications within collective bargaining agreements that protected union jobs by limiting management's ability to substitute capital for labor and (see Steigerwald (2010)).

The United Steel Workers also limited capital-labor substitution with what is known as Rule 2-b in steel industry collective bargaining agreements (see Rose (1998)). This clause limited management's ability to reduce the number of workers assigned to a task, or to introduce new capital equipment that would reduce hours worked or employment (see Strohmeyer (1986)). Section 2-b was the major point of contention in the Steel strike of 1959, as management viewed this clause as limiting their ability to modernize and increase productivity. Disagreement over section 2-b was an important reason why the 1959 strike lasted so long, as the USW argued that management wanted to replace workers with machines, and management complained about productivity, but section 2-b survived after significant federal pressure was placed on management to settle the strike (see Barnard (2004) and Strohmeyer (1986), and see Schmitz (2005) for a broader analysis and review of work rules, productivity, and union job protection.[12]

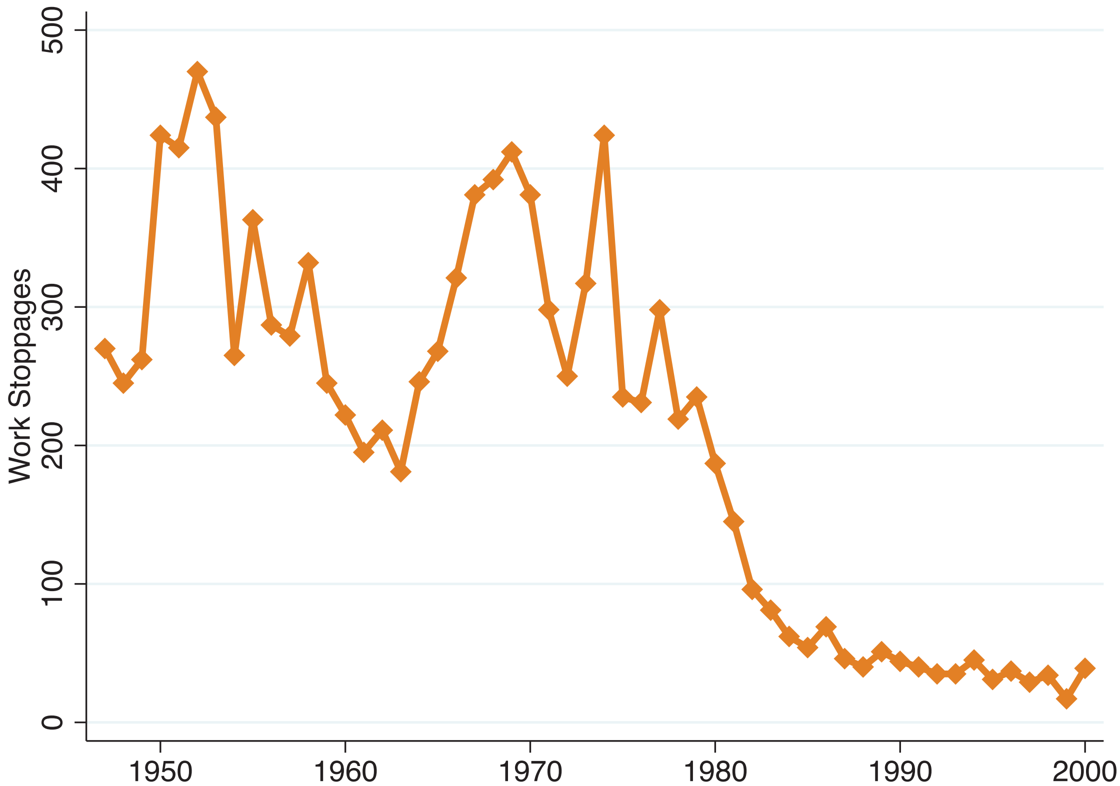
4.2. More Cooperative Rust Belt Labor Relations after 1980

Labor relations in the Rust Belt began to change in the 1980s. A large literature describes how Rust Belt union-management relationships began to shift to more cooperation and efficiency around this time, with a very large decrease in the number of strikes, and the use of strike threats (see Beik (2005), Katz (1985) and Kochan, Katz, and McKersie (1994)).

The change in labor relations is seen clearly in Figure 4.2, which shows the number of strikes per year involving at least one thousand workers from the end of WWII through 2000. The figure shows that the number of large strikes declined remarkably around the early 1980s, from several hundred per year before to less than fifty afterwards. Many studies have analyzed how union bargaining power declined around this time, and much of the literature cites Reagan's 1981 decision to fire striking unionized federal air traffic controllers as a key factor (see McCartin (1986) and

[12]The steel industry tried another approach to resolve labor conflict with the USW by using an experimental bargaining agreement (ENA). This agreement was essentially a no-strike pledge from the USW in return for automatic annual wage increases that consisted of CPI-based cost of living raises, plus an additional three percent annual wage increase beyond the CPI adjustment. While this agreement temporarily removed the strike threat, section 2-b was retained. The ENA was in place between 1974 and 1980 and during this period steel workers achieved the highest wage increases in the country, reflecting unexpectedly high inflation, plus the built-in productivity growth factor that was well in excess of aggregate productivity growth during this period of slow economic growth (see Strohmeyer (1986)).

Figure 3: Work Stoppages Affecting More Than One Thousand Workers



Cloud (2011) and the references therein). Academic studies, as well as the views of industry participants, conclude that the firing of the air traffic controllers and the decertification of their union led to much wider use of permanent replacement workers during strikes, which in turn reduced union bargaining power and the effectiveness of the strike threat.

Leroy (1987) found that firms hired permanent replacement workers during strikes much more frequently in the 1980s than before. Cramton and Tracy (1998) found that the increased use of replacement workers in the 1980s relative to the 1970s significantly affected unions' decisions to strike, and that this factor can account for about half of the decline in strike activity that occurred after the 1970s. In particular, Cramton and Tracy (1998) describe that union leadership warned union members about the reduced effectiveness of strikes in the 1980s.[13] Similarly, George Becker, the President of the United Steel Workers union, remarked that the firing of the PATCO workers "sent a message to corporate leaders that previously unacceptable behavior in collective bargaining

[13] Cramton and Tracy (1998) discuss how The AFL-CIO stated in their 1986 training manual *The Inside Game: Winning With Workplace Strategies* that the increased use of replacement workers had substantially reduced the usefulness of the strike as a bargaining tactic. The training manual notes: "When an employer begins trying to play by the "new rules" and actually force a strike, staying on the job and working from the inside may be more appropriate" (page 5, emphasis in original).

had significantly changed" (see Becker (2000)).

The effect of permanent replacement workers on the effectiveness of the strike threat is also held more broadly. A 1990 GAO survey of both unions, and employers with unionized employees, found that 100 percent of union leaders agreed that the use of permanent replacement workers was much higher in the 1980s compared to the 1970s, and 80 percent of employers agreed with that statement (United States General Accounting Office, 1990).

Research also shows that increased competition in Rust Belt industries promoted more cooperative labor relations. In particular, Clark (1982), Hoerr (1988), Kochan, Katz, and McKersie (1994) and Strohmeyer (1986) describe how management and unions changed their bargaining relationships, including changing work rules that impeded productivity growth, in order to increase the competitiveness of their industries. For example, United Steel Workers President Lloyd McBride described steel industry labor relations in 1982 as follows: "The problems in our industry are mutual between management and labor relations, and have to be solved. Thus far, we have failed to do this" (see Hoerr (1988), page 19).[14]

An important implication of this history is that the decline of the Rust belt coincides with the period of conflicted labor relations between unions and management, and that the stabilization of the Rust Belt coincides with more efficient and cooperative labor relations that began in the 1980s.

4.3. The Impact of Conflicted Labor Relations on Productivity

Research that shows that productivity growth of Rust Belt industries was low compared to other U.S. industries, and also was low compared to the same industries in other countries. Studies also show that conflicted Rust Belt labor relations contributed to low productivity growth within Rust Belt industries through strikes and other aspects of labor relations conflict. These are summarized below.

In terms of cross-country comparisons, Clark (1982) found that post-World War II productivity grew considerably faster among Japanese auto producers, and that Japan had an average \$500 - \$600 cost advantage per vehicle over U.S. auto producers in the 1970s. Katz (1985) finds that this cost differential rose to about \$2000 by the early 1980s. Fuss and Waverman (1991) find that Japanese auto producers had a cost advantage of about 19 percent per vehicle in 1979, even after adjusting for lower capacity utilization among U.S. producers. Jorgenson, Kuroda, and Nishimizu (1987) analyze data from 1960-1985, and find faster productivity growth among Japanese steel

[14]More recently, UAW. President Bob King stated in 2010 that "the old bargaining protocol in the auto industry was one in which we saw each other as adversaries, rather than partners. Mistrust became embedded in our relations...The 21st-century UAW recognizes that flexibility, innovation, lean manufacturing and continuous cost improvement are paramount in the global marketplace" (see Schoenberger (2010)).

producers throughout this period. They estimate that Japanese steel producers achieved lower costs than U.S. producers by the mid-1970s, and that Japan built a wider cost advantage relative to the U.S. after that (see page 22).

A number of studies find that deficient Rust Belt productivity growth was in part caused by conflicted labor relations. Clark (1982), in the National Academy report, describes in detail differences in labor relations between the U.S. and Japan auto producers, and concludes that part of the productivity and quality difference between U.S. and Japanese autos was due to more efficient and cooperative labor relations in Japan. Norsworthy and Zabala (1985) use census data to estimate a translog production function for the U.S. auto industry, and find that strikes depress productivity growth and raise unit costs. Moreover, they find that this phenomena reflects inefficient and uncooperative labor relations between union and management. Lam, Norsworthy, and Zabala (1991) analyze differences in labor relations and bargaining between Japan and the U.S., using an estimated translog cost function, and find that the quality and cooperativeness of labor relations contributes significantly to productivity, and that adversarial labor relations in the U.S. depressed productivity growth.

Katz (1985) uses data from the 1970s, and finds that conflicted labor relations contributed to the deterioration of the U.S. auto industry's productivity growth and their competitiveness with international producers. Flaherty (1987) finds in regression analysis that strike activity significantly reduces real output per hour, particularly during the 1950-78 period. Naples (1981) concludes on the basis of a factor analysis study of conflict and productivity that worker militancy and strikes negatively impacted productivity in the 1950s-1970s.

Similarly, Kuhn (1961) describes that productivity was depressed by frequent wildcat strikes, work slowdowns and worker grievances. An average of 1,241 of these events occurred per year in the 1950s, and involved about 524,000 workers per year. Most of these events were in the auto, steel, rubber, and coal industries. Katz, Kochan, and Keefe (1987) study unionized and non-unionized plants and conclude that poor labor relations, involving grievances, worker resentment, and resistance to technological change lead to lower productivity at union plants. More recently, Krueger and Mas (2004) describe how labor conflict and strikes at Firestone Tires led to the production of low quality tires, which is consistent with labor conflict reducing productivity.

5. Model of Rust Belt's Decline

This section develops a model that formalizes the linkages between competitive pressure, productivity growth, and regional employment shares. The model is tailored to capture the persistent conflicted labor relations in the Rust Belt's labor markets, as well as the rationing of Rust Belt jobs. This requires optimization problems for Rust Belt firms that feature a hold-up problem with a labor union, optimization problems for other firms with undistorted investment decisions, and optimization problems for individual workers, who choose where to locate given their union status and subject to job rationing in the Rust Belt. We also include international trade, so as to evaluate the role of competitive pressure from abroad on the Rust Belt's decline. We then use the model to relate the lack of competitive pressure to the decline in the Rust Belt's share of U.S. employment, and to compare the roles of non-competitive labor markets and competitive pressure from abroad on the Rust Belt's decline.

5.1. Preferences and Technology

Time is discrete and periods are indexed by t. There is a unit measure of workers with preferences over a single consumption good, C_t:

$$\sum_{t=0}^{\infty} \delta^t C_t, \tag{1}$$

where δ is the workers' discount factor, which satisfies $\delta \in (0,1)$. The workers are endowed with one unit of labor each period, which they supply inelastically to the labor market. The final consumption good is produced using inputs from a continuum of sectors, indexed by $i \in [0,1]$, and using the technology:

$$Y_t = \left(\int_0^1 y_t(i)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}}, \tag{2}$$

where $y(i)$ denotes the quantity of input from sector i, and σ is the elasticity of substitution between inputs from any two sectors. We assume that $\sigma > 1$, which implies that inputs from any pair of sectors are gross substitutes. For expositional purposes we drop the time subscript t, whenever possible.

Production takes place in two regions: the *Rust Belt* (r) and the *Rest of the Country* (s). The sectors $i \in (0, \lambda]$ are located in the Rust Belt, and those indexed by $i \in (\lambda, 1]$ are located in the Rest of the Country. In addition, these regions differ in the nature of competition in their labor markets. We describe these differences in market structure shortly.

Similar to the models of Atkeson and Burstein (2008) and Edmond, Midrigan, and Xu (2015), we assume that each of the sectors is populated by a continuum of firms producing differentiated intermediate goods. The firms are indexed by $j \in (0,1)$ and each domestic producer has a foreign counterpart in the same sector. The output of any sector i is a composite of the domestic and foreign intermediate goods in i:

$$y(i) = \left(\int_0^1 y(i,j)^{\frac{\rho-1}{\rho}} + y^*(i,j)^{\frac{\rho-1}{\rho}} dj \right)^{\frac{\rho}{\rho-1}}, \tag{3}$$

where $y(i,j)$ is domestic intermediate good j in sector i, $y^*(i,j)$ is the corresponding foreign intermediate in the same sector, and ρ is the elasticity of substitution between any two varieties of good i, whether home or foreign. Moreover, we follow Atkeson and Burstein (2008) and Edmond, Midrigan, and Xu (2015) and assume that $\rho > \sigma$, meaning the substitutability between any two within-sector intermediates is higher than between a pair of intermediates in two different sectors.

Each good is produced by a single firm :

$$y(i,j) = z(i,j) \cdot n(i,j), \tag{4}$$

where $z(i,j)$ is the domestic firm's productivity and $n(i,j)$ is the labor input chosen by the firm. Each firm takes its own productivity and the productivities of all other firms in the current period as given. Productivity of domestic firms evolves endogenously in the model and we discuss this innovation process in detail below.

5.2. Foreign Sector, Productivity and Trade

Let $z^*(i,j)$ denote the productivity of a foreign firm producing intermediate j in sector i. Moreover, let Z denote the set of all productivities across all domestic and foreign firms, that is, $Z \equiv \{z(i,j)\}_{i,j=0}^1 \cup \{z^*(i,j)\}_{i,j=0}^1$.

In practice, we restrict our attention to symmetric equilibria where domestic productivities are equalized *within* regions and hence take on one of two values, z_r and z_s. Similarly, foreign productivities are z_r^* and z_s^* in regions r and s, respectively. Put differently, z_r denotes the productivity of firms that produce intermediate goods in sectors indexed by $i \in (0,\lambda]$, i.e. those in the Rust Belt, and z_s the productivity of those firms in sectors indexed by $i \in (\lambda, 1]$. Similarly, foreign Rust Belt firms use a technology with productivity z_r^* and Rest of the Country firms with productivity z_s^*. In contrast to the endogenous innovation decisions at home, the foreign productivities evolve exogenously at rate χ, so that $z_s^{*'} = z_s^*(1+\chi)$ and $z_r^{*'} = z_r^*(1+\chi)$.

All intermediate goods can be traded domestically at no cost and internationally at an iceberg-style cost $\tau \geq 1$. This symmetric international trade cost evolves exogenously according to a Markov process, which we describe in more detail below. Lastly, we require trade to be balanced each period.

5.3. Labor Markets and the Union

Labor markets differ by region. In the Rust Belt, labor markets are governed by a labor union, while they are perfectly competitive elsewhere. Each worker's status is either "non-union" or "union member"; let $\upsilon \in \{0,1\}$ represent the union status of a given worker. We assume that the cost of moving workers across space is zero. However, only union members can be hired by Rust Belt producers. Non-union workers can work in the Rest of the Country, or can attempt to work in the Rust Belt by applying for union membership. Any non-union worker choosing to locate in the Rust Belt faces a (time varying) probability F of being offered a union card and hence the opportunity to take a union job. The rate F is a function of the state, though we write it as a number here for convenience. If the worker ends up with a union job, she earns the union wage and becomes a union member (which she remains for life). With probability $1-F$ she does not find work in the Rust Belt, remains non-union, and in addition faces a disutility $\bar{u}$ of having queued unsuccessfully.

Union membership is an absorbing status but each period an exogenous fraction ζ of all workers retire and are replaced with an identical fraction of new workers, who enter as non-union workers. This parsimonious lifecycle specification of the workforce allows us to specify the workers' location decisions in a convenient way, given that union jobs are rationed.

Let U denote the unionization rate in a particular period, i.e. the measure of unionized workers, and let M be the fraction of non-union workers that choose to locate in the Rust Belt. The law of motion for unionization is given by

$$U' = (1-\zeta)[U + MF(1-U)], \tag{5}$$

so that next period's unionization rate is the measure of non-retiring existing union members plus the measure of (formerly non-union) workers that chose to locate in the Rust Belt and successfully became union members in the current period.

Non-union workers receive the competitive wage each period, which we normalize to unity. Union workers receive the competitive wage plus a union rent, which is a share of the profits of firms in the Rust Belt. We assume that profits are split each period between the union and Rust Belt firms according to Nash bargaining, as in Grout (1984). This assumption provides a simple way of capturing the persistent holdup problem that characterized Rust Belt labor relations for decades, as we discussed in Section 4. The parameter β is the union's bargaining weight, which evolves exogenously over time according to a Markov process, described below.

5.4. Exogenous State Variables

There are two exogenous state variables in the model: the union bargaining power, β, and the trade cost, τ. We assume that these variables take on one of two pairs of values: (β_H, τ_H) or (β_L, τ_L), where $\beta_H > \beta_L > 0$ and $\tau_H > \tau_L > 0$. In the H state, both the union's bargaining power and the iceberg costs are high; in the L state they are more moderate. We initiate the economy in the H state, which we take to represent the period right after the end of the war, and let it evolve according to the following Markov chain:

	(β_H, τ_H)	(β_L, τ_L)
(β_H, τ_H)	$1-\varepsilon$	ε
(β_L, τ_L)	0	1

where ε represents the probability of transitioning to a state where workers have less bargaining power and trade frictions are lower. In this particular application, the L state is absorbing. As we show later, this specification, while simple, captures the main features of the wage premiums and trade patterns we observe over the time period in question.

5.5. Endogenous State Variables

It is useful to summarize the endogenous state variables, for clarity. There are two aggregate endogenous state variables: Z, which is the set of firms' productivities, and U, which is the unionization rate. In addition, each individual worker has status $\upsilon \in \{0,1\}$, which governs whether they are a union member or not. Each individual firm has a state z, which is its productivity. In a *symmetric equlibrium*, as we describe above, this productivity takes on one of two values: z_r for firms in the Rust Belt, and z_s for firms in the Rest of the Country.

5.6. Domestic Firms' Problem

We now consider the problem of a domestic producer of a single intermediate good. It is useful to divide the firm's problem up into its static and dynamic components. The firm's static problem is to maximize current-period profits by choosing prices and labor inputs for domestic consumption and exports. For a firm with productivity z, the formal maximization problem is:

$$\Pi(Z,U,z;\beta,\tau) = \max_{p,\, p^{EX},\, n,\, n^{EX},\, y,\, y^{EX}} \left\{ p \cdot y + p^{EX} \cdot y^{EX} - \left(n + n^{EX}\right) \right\}, \tag{6}$$

subject to

$$
\begin{aligned}
y &= z \cdot n, \\
y^{EX} &= z \cdot n^{EX}, \\
y &= P(Z,U;\beta,\tau)^{\sigma-1} \cdot P_{\ell}(Z,U;\beta,\tau)^{\rho-\sigma} \cdot X(Z,U;\beta,\tau) p^{-\rho}, \text{ and} \\
y^{EX} &= P^{*}(Z,U;\beta,\tau)^{\sigma-1} \cdot P_{\ell}^{*}(Z,U;\beta,\tau)^{\rho-\sigma} \cdot X^{*}(Z,U;\beta,\tau) \left(\tau \cdot p^{EX}\right)^{-\rho} \tau,
\end{aligned}
$$

where y denotes domestic sales and y^{EX} are the quantities produced for exports. Analogously, n and n^{EX} are the labor inputs and p and p^{EX} the factory gate (f.o.b.) prices corresponding to these two destinations. The first two constraints are the production functions (for the home and export market, respectively) and the two remaining ones are an individual firm's demand functions for domestic sales and exports. $X(Z,U;\beta,\tau)$ and $P(Z,U;\beta,\tau)$ represent total expenditures and the aggregate price index, and $P_{\ell}(Z,U;\beta,\tau)$ is the sectoral price index for $\ell \in \{r,s\}$. Asterisks denote the corresponding price indices and aggregate expenditure abroad. The firm's optimal factory gate price is the standard Dixit-Stiglitz monopolist markup, regardless of destination:

$$
p = \tfrac{\rho}{\rho-1} \tfrac{w}{z} = p^{EX}. \tag{7}
$$

Since domestic labor is the numeraire and the optimal price is a constant markup over marginal cost for all producers, we have $X(Z,U;\beta,\tau) = \frac{\rho}{\rho-1}$ and, analogously, $X^{*}(Z,U;\beta,\tau) = \frac{\rho}{\rho-1} w^{*}(Z,U;\beta,\tau)$. The foreign wage, $w^{*}(Z,U;\beta,\tau)$, is an equilibrium object and we derive it formally in section 5.8.

In a symmetric equilibrium, the price indices are the usual CES aggregates over the prices of individual goods and sectors. More formally, for $\ell \in \{R,S\}$,

$$
\begin{aligned}
P_{\ell}(Z,U;\beta,\tau) &= \left(p_{\ell}^{1-\rho} + (\tau p_{\ell}^{*})^{1-\rho}\right)^{\frac{1}{1-\rho}}, \\
P_{\ell}^{*}(Z,U;\beta,\tau) &= \left((\tau p_{\ell})^{1-\rho} + p_{\ell}^{*\,1-\rho}\right)^{\frac{1}{1-\rho}}, \\
P(Z,U;\beta,\tau) &= \left(\lambda P_{R}^{1-\sigma} + (1-\lambda) P_{S}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}, \\
P^{*}(Z,U;\beta,\tau) &= \left(\lambda P_{R}^{*\,1-\sigma} + (1-\lambda) P_{S}^{*\,1-\sigma}\right)^{\frac{1}{1-\sigma}},
\end{aligned}
$$

where p_{ℓ} is given by (7) and the foreign price is $p_{\ell}^{*} = \frac{\rho}{\rho-1} \frac{w^{*}}{z^{*}}$.

The firms' dynamic problem is to choose how much to innovate. Innovation raises the firm's future productivity and requires an investment of final goods today. By this we have in mind a broad notion of investment which includes anything that increases labor productivity, such as new technologies embodied in capital equipment. We assume that increasing productivity by x percent requires $C(x,z,Z)$ units of the final good, where $C(x,z,Z)$ is convex in x and depends on the firm's current productivity, z, and the productivity of other firms in the economy (both at home and abroad), denoted by Z. Firms purchase each unit of the final good at price $P(Z,U;\beta,\tau)$. The law of motion for the firm's idiosyncratic productivity is $z' = z(1+x)$.

An individual firm's dynamic problem depends on the region (sector) to which it belongs. Let z_s be the productivity of a firm in the Rest of the Country. Its dynamic problem is given by the following Bellman equation:

$$V^s(Z,U,z_s;\beta,\tau) = \max_{x_s>0} \{ \Pi^s(Z,Uz_s;\beta,\tau) - P(Z,U;\beta,\tau) \cdot C(x_s,z_s,Z) \\ + \delta E[V^s(Z',U',z'_s;\beta',\tau')] \}, \tag{8}$$

where $z'_s = z_s(1+x_s)$, and given some perceived law of motion for Z, denoted $Z' = G(Z,U;\beta,\tau)$. Thus, firms choose their productivity increase x_s to maximize static profits minus investment costs plus the discounted value of future profits, which reflects the higher productivity resulting from today's investment.

The dynamic problem for a Rust Belt firm, in contrast, is given by

$$V^r(Z,U,z_r;\beta,\tau) = \max_{x_r>0} \{ (1-\beta)\Pi^r(Z,U,z_r;\beta,\tau) - P(Z,U;\beta,\tau) \cdot C(x_r,z_r,Z) \\ + \delta E[V^r(Z',U',z'_r;\beta',\tau')] \}, \tag{9}$$

where $z'_r = z_r(1+x_r)$ and the perceived law of motion for Z is, again, $Z' = G(Z,U;\beta,\tau)$. The difference between the Rust Belt firms' problem and that of other firms is that Rust Belt firms keep only a fraction $(1-\beta)$ of each period's profits. As we discuss further below, this leads to a hold-up problem that reduces investment in the Rust Belt relative to the rest of the country.

5.7. Worker's Problem

The problem of an individual worker is where to locate each period, so as to maximize expected discounted utility. The individual state variable of a given worker is her union status, $\upsilon \in \{0,1\}$, plus the aggregate states Z and U. Also relevant for the worker's decision are the union rent and the union admission rate functions, $R(Z,U;\beta,\tau)$ and $F(Z,U;\beta,\tau)$, that describe the additional payment made to a union worker relative to a non-union worker, and the probability of obtaining a union card and hence the right to work a union job.

Let $W^r(Z,U,\upsilon;\beta,\tau)$ and $W^s(Z,U,\upsilon;\beta,\tau)$ be the values of locating in the Rust Belt and Rest of the Country. The worker's value function is:

$$W(Z,U,\upsilon;\beta,\tau) = \max\{W^r(Z,U,\upsilon;\beta,\tau), W^s(Z,U,\upsilon;\beta,\tau)\}. \tag{10}$$

First, consider locating in the Rust Belt. For non-union workers, i.e. $\upsilon = 0$, the value is given by

$$W^r(Z,U,0;\beta,\tau) = F(Z,U;\beta,\tau)\{1 + R(Z,U;\beta,\tau) + \delta(1-\zeta)E[W(Z',U',1;\beta,\tau)]] + \tag{11}$$

$$(1 - F(Z,U;\beta',\tau'))[1 - \bar{u} + \delta(1-\zeta)E[W(Z',U',0;\beta',\tau')]\}. \tag{12}$$

In other words, when trying to locate in the Rust Belt, a non-union worker gets a union card with probability $F(Z,U;\beta,\tau)$ which entitles her to work in a unionized firm. In this case she gets the competitive wage (normalized to one) plus the union rent, plus the expected discounted value of union membership in the future. With probability $1 - F(Z,U;\beta,\tau)$ she does receive a card, in which case she gets the competitive wage minus the utility cost of "queueing" unsuccessfully for union membership, plus the expected discounted value of not being a union member.

For union members, i.e. $\upsilon = 1$, the value of locating in the Rust Belt is:

$$W^r(Z,U,1;\beta,\tau) = 1 + R(Z,U;\beta,\tau) + \delta(1-\zeta)E[W(Z',U',1;\beta',\tau')], \tag{13}$$

which is the competitive wage plus the union wage rent today, plus the expected discounted value of being a union member in the future. Note that since union members always earn the union wage premium and have no incentive to leave the union; they exit only via attrition, at rate ζ.

Next, consider locating in the Rest of the Country. In this case, a worker with union status υ has value function:

$$W^s(Z,U,\upsilon;\beta,\tau) = 1 + \delta(1-\zeta)E[W(Z',U',\upsilon;\beta',\tau')], \tag{14}$$

which is the competitive wage today, plus the expected discounted value of having union status υ in the future. Non-union workers in the Rest of the Country get the competitive wage today plus the expected discounted utility of being a non-union worker in the future. Union members in the Rest of the Country get the competitive wage today plus the expected discounted utility of being a union member in the future.

The worker's problem is easy to characterize. As long as union rents are positive, union members will strictly prefer to locate in the Rust Belt. In contrast, non-union workers will be indifferent between locating in the two regions only for one particular job finding rate, $F(Z,U;\beta,\tau)$, all else equal. Following previous spatial models, such as the model of Desmet and Rossi-Hansberg

(2014), we focus on an equilibrium where (non-union) workers are indifferent across locations. We also restrict attention to the symmetric recursive competitive equilibrium where firms in each region make the same decisions and have the same productivity level each period.

5.8. Trade Balance and Foreign Wage

We require balanced trade each period. Put differently, expenditures on goods from abroad must equal foreign expenditures on exports from the US. Since we are focusing on a symmetric equilibrium, we can write the balance condition as follows:

$$\lambda p_r^* y_r^{*EX} + (1-\lambda) p_s^* y_s^{*EX} = \lambda p_r y_r^{EX} + (1-\lambda) p_s y_s^{EX}, \tag{15}$$

where the superscript EX denotes exports.[15] US expenditures on foreign goods are on the left hand side of the equation and foreign expenditures on US goods are on the right hand side. After substituting quantities with the expressions in the constraints of (6) and those for aggregate expenditures at home and abroad, we can close the model by solving the trade balance equation, which has a single unknown, the foreign wage rate w^*:

$$w^* = \frac{P(w^*)^{\sigma-1}\left(\lambda p_r^*(w^*)^{1-\rho} P_r(w^*)^{\rho-\sigma} + (1-\lambda) p_s^*(w^*)^{1-\rho} P_s(w^*)^{\rho-\sigma}\right)}{P^*(w^*)^{\sigma-1}\left(\lambda p_r^{1-\rho} P_r^*(w^*)^{\rho-\sigma} + (1-\lambda) p_s^{1-\rho} P_s^*(w^*)^{\rho-\sigma}\right)}. \tag{16}$$

5.9. Cost Function

We select the functional form for the cost function such that the model has several desirable properties. As is standard, we want the cost of innovation to be increasing and convex in the input of final goods. In addition, the dynamic program as a whole must be homogeneous of degree zero with respect to the state variables and hence invariant to the scale of all productivities. This allows us to express all productivities relative to a benchmark producer, which we choose to be a Rest of the Country firm. More specifically, this is equivalent to requiring that the cost of innovation in units of the numeraire, $C(x,Z,z) \cdot P(Z,U;\beta,\tau)$, be homogeneous of degree zero with respect to all the productivities. Together, these properties give us all the tractability we need to solve and parameterize the model.

As we show in the Appendix, the only cost function that satisfies the homogeneity requirement is:

$$C(x,Z,z) = \alpha x^{\gamma} \frac{z^{\rho-1}}{D(Z)}, \tag{17}$$

[15] For instance, y_r^{*EX} denotes the quantity of foreign Rust Belt goods exported to the United States.

where the denominator, $D(Z)$, is:

$$D(Z) = \left(\int_0^1 \left\{ \int_0^1 \left[z(i,j)^{\rho-1} + z(i,j)^{*\rho-1} \right] dj \right\}^{\frac{1-\sigma}{1-\rho}} di \right)^{\frac{2-\rho}{1-\sigma}}. \tag{18}$$

The parameters α and γ govern the scale and curvature of the cost function.[16]

In addition, a frictionless version of this economy can generate a balanced growth path. In particular, when no country has a comparative advantage (either because the economy has converged to such a steady state or because we select initial conditions accordingly), trade is free ($\tau = 1$), and the unions have no bargaining power ($\beta = 0$), we can characterize the long-run (global) growth rate by solving a single non-linear equation in a single unknown, x_{SS}:

$$(1-\delta)\gamma\alpha x_{SS}^{\gamma-1} = \delta(1+x_{SS})^{-1}\left(\left(\frac{\rho}{\rho-1}\right)^{1-\rho} \left(1+\mu^{\frac{\rho-1}{\rho}}\right) + \alpha x_{SS}^{\gamma} \right), \tag{19}$$

where μ denotes Foreign's absolute advantage, i.e. $\mu Z_R = Z_R^*$ and $\mu Z_S = Z_S^*$. Put differently, any individual firm in this economy, regardless of location (country and region) and idiosyncratic productivity, will innovate at rate x_{SS}. The intuition is that the cost function makes it easier to innovate for firms that are less productive than average, which gives less productive firms an incentive to innovate more. On the other hand, larger firms have a higher incentive to innovate due to a ?market size? effect, since they can spread innovation costs over more units sold, since their higher productivity gives them a larger market. Our cost function has these two forces exactly offset. In the Appendix we show the derivation of this expression from the first-order and envelope conditions associated with the Bellman equations (8) and (9) as well as the expression (16) for the foreign wage.

6. Quantitative Analysis

We now turn to a quantitative analysis of the dynamic model to assess how much of the employment share decline from 1950-2000 can plausibly be accounted for by low competitive pressure in Rust Belt labor markets. We calibrate the differences in labor market competition between the Rust Belt and the Rest of the Country using the evidence on wage premiums we presented in Section 3. We find that our baseline calibration of the model accounts for around half of the observed drop in

[16] In the symmetric equilibrium, the denominator simplifies to:

$$D(Z) = \left(\lambda \left[Z_R^{\rho-1} + Z_R^{*\rho-1} \right]^{\frac{1-\sigma}{1-\rho}} + (1-\lambda) \left[Z_S^{\rho-1} + Z_S^{*\rho-1} \right]^{\frac{1-\sigma}{1-\rho}} \right)^{\frac{2-\rho}{1-\sigma}},$$

where $Z_.$ and $Z_.^*$ denote the common productivities in the two regions at home and abroad, respectively.

the Rust Belt's manufacturing employment share.

6.1. Parameterization

We choose a model period to be five years, and, accordingly, set the discount rate to $\delta = 0.96^5$. For the elasticity of substitution we set $\sigma = 2.7$, based on the work of Broda and Weinstein (2006), who estimate elasticities of substitution between a large number of goods and find median elasticities between 2.7 and 3.6, depending on the time period and degree of aggregation. We set the elasticity of substitutions between varieties to $\rho = 4$, which delivers a markup of 33 percent, consistent with those estimated by Collard-Wexler and De Loecker (2015) for the U.S. steel industry. In terms of initial conditions, we set $z_{S,0} = z_{R,0} = z^*_{S,0} = 1$, though we have found that our results are not sensitive to these values given our calibration strategy. For the transition matrix for β and τ, we choose a value of $\varepsilon = 1/6$, corresponding an expected 6 model periods in the initial high state, or 30 years.

Table 3: Parameters Used in Quantitative Analysis

Moment	Value
δ – discount factor (five-years)	0.82
σ – elasticity of substitution between sectors	2.70
ρ – elasticity of substitution between varieties	4.00
ε – probability of transition to more competitive state	0.17
λ – share of sectors in Rust Belt	0.53
γ – curvature term in cost function	1.80
α – linear term in cost function	7.08
χ – productivity growth rate of foreign sector	0.02
τ_{pre} – trade costs low-competition state	3.50
τ_{post} – trade costs in high-competition state	2.68
β_{pre} – labor bargaining in low-competition state	0.36
β_{post} – labor bargaining in high-competition state	0.12
$z^*_{R,0}$ – initial foreign productivity level	2.30

We calibrate the remaining nine parameters to jointly match nine moments in the data. The parameters to calibrate are: (i) λ, the share of goods produced in the Rust Belt, (ii and iii) γ and α, the curvature and linear terms in the investment cost function, (iv) χ, the productivity growth rate of the foreign sector, (v and vi) τ_{pre} and τ_{post}, the trade costs pre- and post-1980,(vii and viii) β_{pre} and β_{post}, the labor bargaining terms pre- and post-1980, and (ix) $z^*_{R,0}$ and , the initial foreign productivity levels.

Table 4: Moments Targeted: Model vs Data

Moment	Model	Target
Initial employment percent of Rust Belt	51.30	51.30
Innovation as a percent of GDP	8.50	8.50
Long-run annual GDP growth rate (%)	1.80	1.80
Aggregate import share, 1950-1980 average	3.99	4.00
Aggregate import share, 1980-2000 average	8.98	9.00
Rust Belt wage premium, 1950-1980 average	12.00	12.00
Rust Belt wage premium, 1980-2000 average	4.00	4.00
Rust Belt import share, 1950-1980 average	7.99	8.00

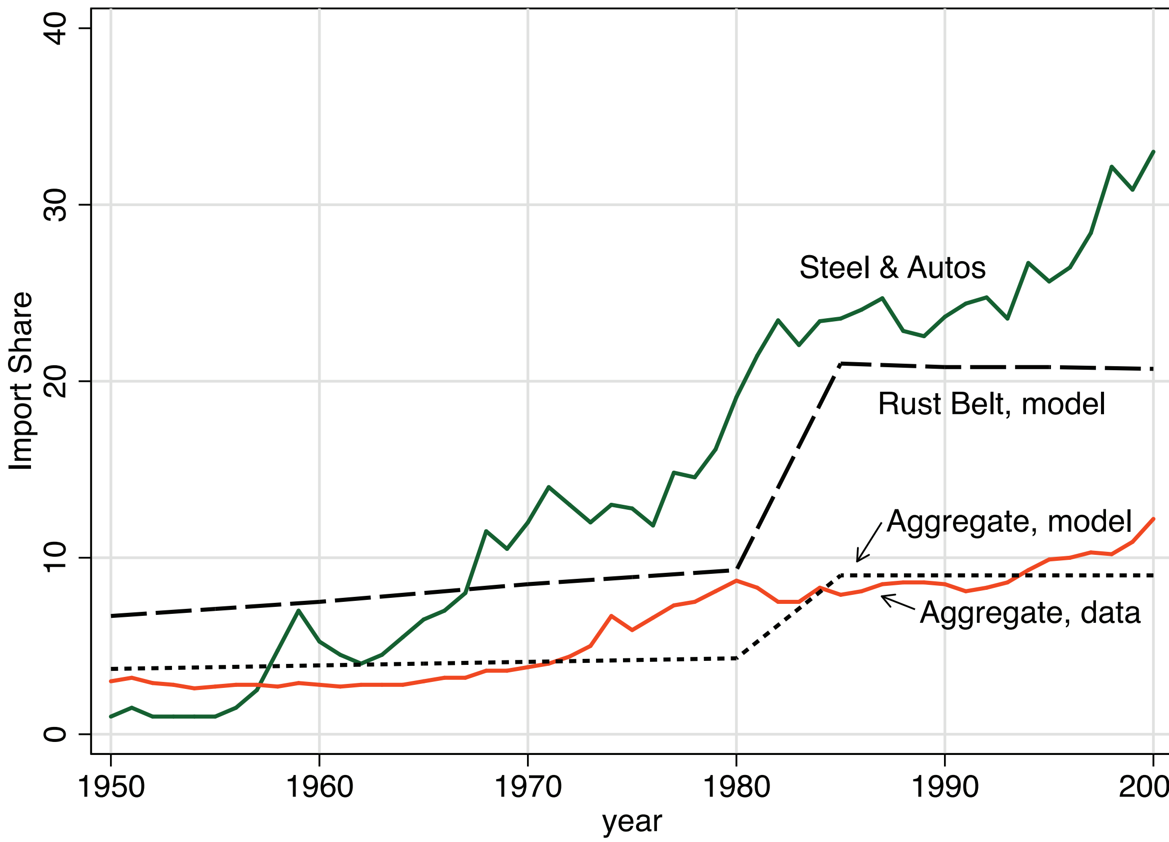
The nine moments we target are: (i) the initial employment share of 51 percent in the Rust Belt, corresponding to the actual share in 1950; (ii) an average innovation investment-to-GDP ratio of 8.5 percent, which is the average ratio of investments in R&D, advertising and other intangibles to GDP in the United States (Corrado, Hulten, and Sichel, 2005; McGrattan and Prescott, 2010; Acemoglu, Akcigit, Bloom, and Kerr, 2013); (iii) a long-run output growth rate of 1.8 percent per year; (iv) a foreign output growth rate of 2 percent per year; (v and vi) an average aggregate import share of 4 percent and 9 percent in the periods pre- and post-1980; (vii and viii) the Rust Belt wage premium of 12 percent and 4 percent pre- and post-1980, as in Figure 3; (ix) the Rust Belt's average import shares pre-1980 of 8 percent, which we proxy by the average import share in automobiles and steel.

Table 3 reports the value of each parameter used in the calibration. The model matches the desired moments quite well, and in all cases to the second decimal place. For completeness we report each moment and its model counterpart in Table 4.

Figure 4 displays the aggregate and Rust-Belt import shares in the model and data. The green solid line is the average import share in the automobile and steel industries, which we use as a crude proxy for the Rust Belt's import share. Steel and automobiles are among the most prominent Rust Belt industries, and the only two for which we could find data on import shares going back to 1950.[17] The red solid line is the aggregate import share, which we acquired from FRED. The model's calibrated import shares in the model are displayed in Figure 4 as the two dashed lines. While stylized, our model does deliver some of the key features of the import data, namely the sharp increase around 1980, the greater increase in the Rust Belt's import share, and (some of) the steady secular increases in import shares throughout the period.

[17] We computed the steel import shares using data on imports and output from the American Steel Institute and from Wards Auto, respectively.

Figure 4: Import Shares: Model and Data



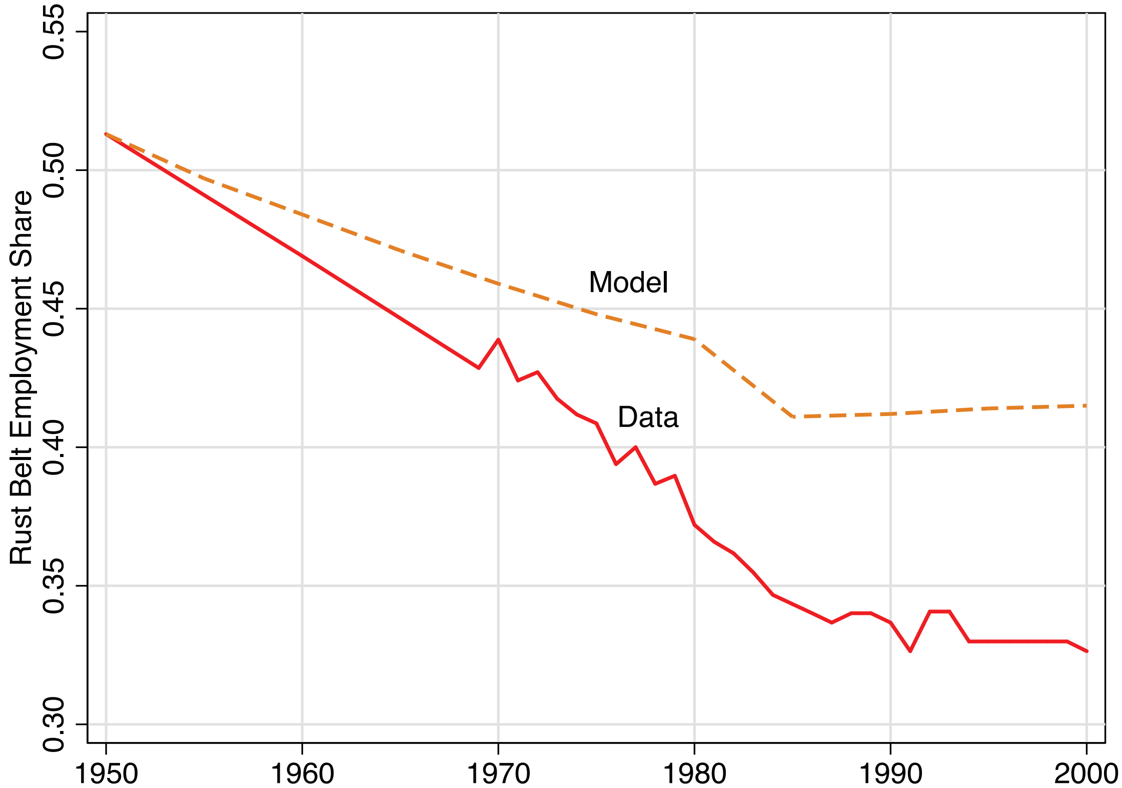
6.2. Quantitative Predictions

Figure 5 plots the model's manufacturing employment share of the Rust Belt from 1950 to 2000 and the data. The first salient feature of the figure is that the model predicts a large secular decline in the Rust Belt's employment share, similar to the data. Overall, the model predicts a drop of 9.8 percentage points, compared to 18 percentage points in the data. Thus, the model accounts for 54 percent of the overall decline in the data.

A second salient feature of Figure 5 is that the model's predicted decline is more pronounced between 1950 and 1980 than in later years, and that, again, mirrors the decline in the data. The model predicts a drop of 10.2 percentage points until 1980, compared to a 14.3 percentage point drop in the data. After 1980, the Rust Belt's employment share predicts a modest gain of 0.4 percentage points, compared to a decline of 2.5 percentage points in the data.

Why does the model predict a steeper decline before 1980 than afterwards? The reason is that low competitive pressure before 1980 depresses innovation in the Rust Belt, and thus lowers productivity growth. This persistent cross-regional difference in productivity growth leads to a persistent

Figure 5: Manufacturing Employment Share in Rust Belt: Model and Data



rise in the relative price of Rust Belt goods, which in turn leads to a persistent shift in economic activity out of the Rust Belt. After 1980, when competitive pressure increases, two effects play important roles. First, the decrease in trade costs imply that the Rust Belt's employment share drops sharply, since the foreign sector has a comparative advantage in the goods that the Rust Belt produces. In the data this is visible in the manufacturing sector right after 1980; in the model, the decline is 3.1 percentage points from 1980 to 1985 alone. The second effect is that the greater competitive pressure (lower values of β) reduces the hold-up problem, which increases investment and productivity growth. This in turn arrests the decline in the Rust Belt's share of employment. In the data, the Rust Belt's share of employment is largely flat after 1985, while the model predicts an increase of 0.6 percentage points.[18]

While we do not target labor productivity growth rates in our calibration, the model performs well from 1950-1980 in this respect. It generates an average growth rate of 1.7 percent annually in the Rust Belt, compared to 2.0 percent in the data. The corresponding growth rates for the Rest of the Country are 2.4 percent (model) and 2.6 percent (data). Thus, the model delivers rates and

[18] Another force that may have served to stabilize the Rust Belt's share of manufacturing is that since the 1990s, imports have mainly affected areas outside the Rust Belt. See (Autor, Dorn, and Hanson, 2013b).

regional rate differentials that track their empirical counterparts reasonably closely in this period. After 1980, the Rust Belt's productivity growth rises sharply in the data up to to 4.2 percent per year on average. The model also predicts a rise in productivity growth, but not as sharp as in the data. In the model, productivity growth rises up from 1.7 percent to 2.5 percent per year.[19]

The model's predictions for import shares in the Rust Belt after 1980 are not targeted directly, but, as in the data, are substantially higher than in the aggregate. In the data, Rust Belt import shares (proxied by automobiles and steel) rise sharply around 1980 from just over 10 percent to around 25 percent. In the model, import shares are around 10 percent in 1980 and rise to 21.3 percent on average afterwards. Part of the reason the model delivers the much higher import share in the Rust Belt than in the aggregate is the exogenous comparative advantage of the foreign sector in Rust Belt goods chosen to match the pre-1980 import shares. But much of the model's success comes from the endogenous comparative advantage of the foreign sector brought about by the Rust Belt's lack of investment in the decides prior to the fall in trade costs.

Several other features of the Rust Belt's economy in the model are consistent with the data. The investment-to-GDP ratio – which is not targeted directly – is lower in the Rust Belt than in the rest of the economy, particularly in the period before 1980 when competitive pressure was at its lowest. In the model, the investment-to-value added ratio averages 5.5 percent in the Rust Belt, compared to 10.3 percent in the rest of the country. Similarly, investment rates as proxied by R&D in Rust Belt industries are low in the data. Moreover, direct measures of technology adoption support our view that prominent Rust Belt industries were lagging behind. We present this evidence in more detail in Section 7.

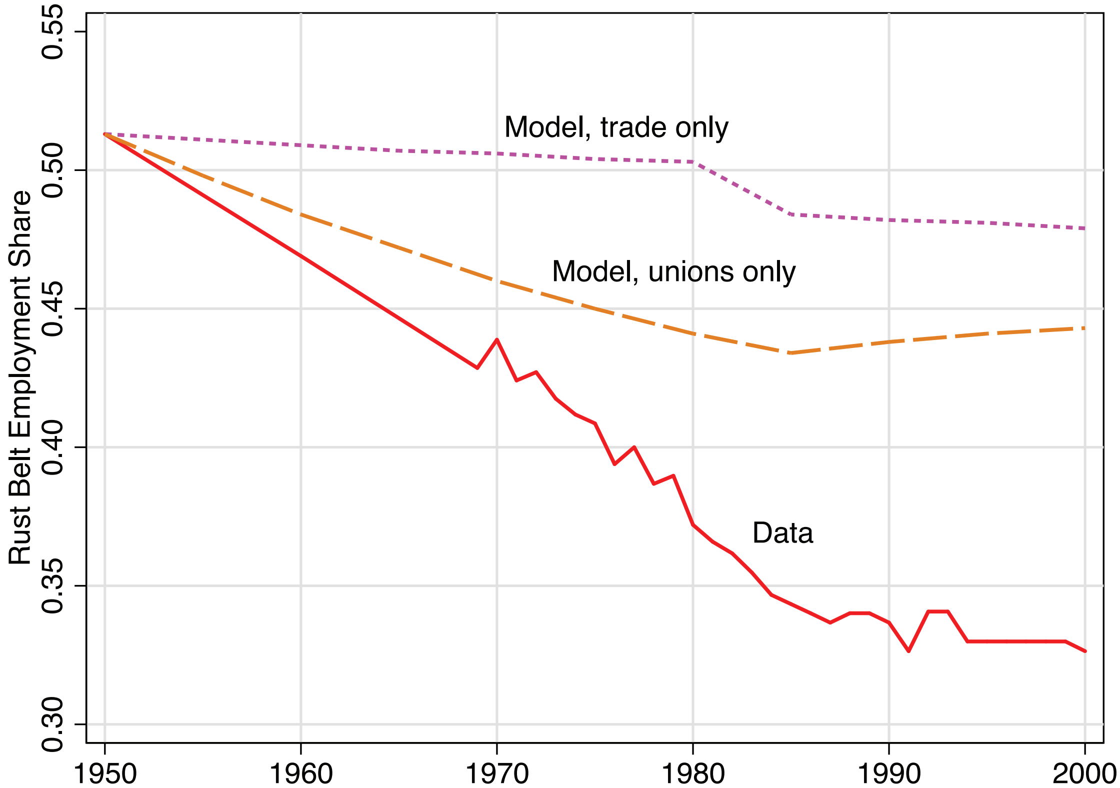
6.3. Decomposition of Rust Belt's Decline

The quantitative results above provide two reasons for the Rust Belt's decline. The timing and nature of these shocks provide different mechanisms that together explain the majority of the Rust Belt's decreasing employment share from 1950 to 2000. In this section, we decompose the results into the model's quantitative predictions into the labor-market competition channel and the import competition channel.

We consider two alternative counterfactual scenarios. In the first, we eliminate the import channel, and keep the trade costs at the same level from 1950 to 2000. In particular, we raise τ_{post} to equal τ_{pre}, leave all other parameters the same, and then simulate the model's predictions as before. We

[19]We plot the model's productivity growth rates by region in Appendix Figure C.1. Some of the additional productivity increases after 1980 may have come from improved work practices and reduction in union work rules, neither of which we model explicitly. See Schmitz (2005) and Dunne, Klimek, and Schmitz (2010) for evidence of reductions in union work rules raised productivity in the iron ore and cement industries in the 1980s.

Figure 6: Decomposing the Rust Belt's Decline



call this the "trade only" counterfactual. In the second, we eliminate the labor market distortions channel, and keep the union bargaining power the same from 1950 to 2000. We do this by reducing β_{pre} to equal β_{post} and keeping all else as in the original calibration. We call this the "union only" counterfactual.

Figure 6.3 plots the model's predicted employment shares in the Rust Belt under the two counterfactuals. In the trade only counterfactual (short dashed line), the Rust Belt has a very slight decline from 1950 to 1980, which is quite counterfactual to the large decline present in the data. In 1980, the model predicts a decline of 1.9 percentage points, which is similar to the actual decline, and afterwards the model predicts a very slight decline, as in the data. In the unions only counterfactual, the model predicts a substantial secular decline of 7.2 percent through 1980, compared to 7.5 percent in the main quantitative model, and to 14.3 percent in the data. After 1980, the unions-only model predicts a modest increase in the Rust Belt's share, as it catches up (somewhat) to the rest of the country.

In summary, the unions-only model does a much better job of explaining the bulk of the Rust Belt's decline, which came before 1980. The trade-only model predicts almost no gain until 1980, when most of the Rust Belt's decline already occurred. The trade-only model does help understand the dip of the early 1980s, though this is a relatively minor part of the region's overall decline. Both counterfactuals are consistent with the post 1980 period, though the Rust Belt didn't decline much then in the data.

6.4. Sensitivity Analysis

We next present several sensitivity analyses. We begin by looking at how the model's predicted employment share decline of the Rust Belt varies with different targets for the elasticity of substitution. We consider two alternative values of σ: a lower value of 2, similar to the estimated value of 1.7 by Acemoglu, Akcigit, Bloom, and Kerr (2013), and a higher value of 3, closer to the middle of the range of estimates by Broda and Weinstein (2006). Each time we re-calibrate the other parameters to match the moments laid out in the previous section. We find that when the elasticity is set to 2, the Rust Belt's employment share drops by 8.7 percentage points, compared to 9.8 in the benchmark calibration. With a higher elasticity of 3, the Rust Belt loses 11.6 percentage points. The intuition for why a larger σ implies a larger decline is that a higher elasticity, for a given differential in productivity growth, leads households to substitute away from Rust Belt goods more aggressively. We conclude that within a plausible range of σ, the model accounts for between 48 percent to 64 percent of the Rust Belt's decline, similar to our benchmark value of around one half.

The second sensitivity analysis is over the parameter ρ, which governs the inner elasticity of substitution between varieties. When we choose a lower value of 3.5, rather than the benchmark value of 4, we get a decline of 9.5 percent. A higher value of 4.5 gives a decline of 9.4 percent, both similar to the benchmark decline. The intuition is that a higher ρ leads to a faster decline for the period pre 1980, as consumers substitute away from Rust Belt goods faster, but then a faster catch-up after 1980, since ρ affects the curvature in the cost function. These two forces largely offset each other so that alternative values of ρ around the benchmark make little overall difference on model's overall predicted decline.

Finally, we consider sensitivity to γ, which controls the curvature of the investment cost function, and which is the major factor impacting the share of output devoted to investment. We consider two alternative parameterizations that target investment shares of 8 percent and 9 percent, respectively, rather than the 8.5 percent target from the benchmark experiment. In these parameterizations, we maintain the 1.8 percent steady-state growth target – which requires a change in $\bar{c}$ – and fix β, λ, and σ at their baseline values. The Rust Belt's employment share falls 9.6 percentage points when investment share is 8 percent, compared to the 9.8 percentage points in the benchmark. When we instead target a 9 percent investment-to-output ratio, the Rust Belt looses 10.3 percentage points. The higher investment rate leads to a sharper decline of the Rust Belt since holding up innovation

Table 5: Sensitivity Analysis

Alternative Specification	Rust Belt Employment-Share Decline
Lower outer elasticity, $\sigma = 2.0$	8.7
Benchmark, $\sigma = 2.7$	9.8
Higher outer elasticity, $\sigma = 3.0$	11.6
Lower inner elasticity, $\rho = 3.5$	9.5
Higher inner elasticity, $\rho = 4.5$	9.4
Investment/GDP of 8 percent	9.6
Investment/GDP of 9 percent	10.3

Note: Rust Belt Employment-Share Decline is the percentage point decline in the share of manufacturing employment in the Rust Belt from 1950 to 2000.

now leads to lower relative productivity growth.

7. Supporting Evidence

In this section we present additional evidence supporting the model's predictions. We first present industry-level evidence showing that industries that had the biggest differences in unionization rates between the Rust Belt and rest of the country tended to have the largest differences in employment growth rates. We then discuss some direct evidence that expenditures on research and development (R&D) and technology adoption were relatively low in some important Rust Belt industries. Finally, we look at evidence from the cross section of U.S. cities, and show that cities that payed the highest wage premiums in 1950 tended to have the lowest employment growth from 1950 to 2000. This evidence supports our theory that a lack of competition and low innovation played an important role in the decline of the Rust Belt.

7.1. Industry-Level Unionization and Employment Growth

In this section we compare measures of labor-market competition and employment growth at the industry-region level. In particular, we compare differences in unionization rates between the Rust Belt and rest of the country, in each industry, to differences in average annual employment growth over the post-war period. We ask whether industries with the biggest differences in unionization rates across regions had disproportionately lower employment growth in the more unionized regions. We find that, on average, they do.

The first available nationally representative surveys that include questions about unionization status came in the 1980s, as part of the CPS (Flood, King, Ruggles, and Warren, 2015). We draw on

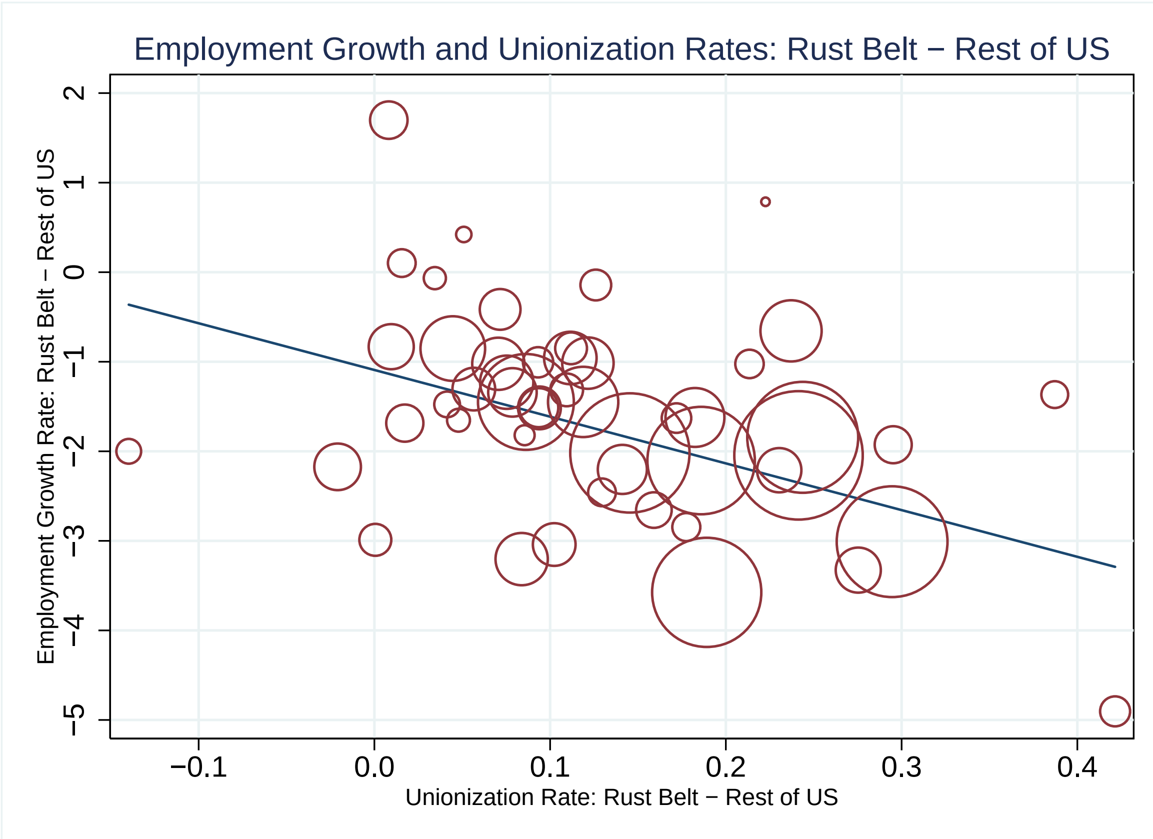


Figure 7: Unionization and Employment Growth: Rust Belt Minus Rest of United States

pooled data from 1983-1989, which are the first five years of available data, and restrict attention to the 50 manufacturing industries with non-zero employment in each census between 1950 and 2000. We compute the fraction of workers covered by a union in each 2-digit census industry in two regions: the Rust Belt, and the rest of the country. We also compute average annual employment growth in each 2-digit census industry from 1950 to 2000 in the same two regions. We then compute the simple difference in unionization rates and employment growth rate for each industry.

Figure 7 plots the difference in unionization rate (x-axis) against the difference in employment growth rate (y-axis). Each industry is weighted in the figure by its employment in 1950. As the figure shows, the two variables are negatively correlated with one another. The correlation coefficient is -0.51, with a p-value less than one percent. In other words, industries with the biggest differentials in unionization rates between the Rust Belt and rest of country tended to have the lowest employment growth rates in the Rust Belt relative to the rest of the country.

We find that this negative correlation holds using several alternative measures of labor-market competition and employment declines. Across industries, the correlation between the unionization differential and Rust Belt's employment share decline is -0.43 with a p-value of less than one percent. The correlation between the ratio of average wages in the Rust Belt and the rest of the country and the employment growth rate differential is -0.40 with a p-value of one percent. In summary, this industry-level evidence support our thesis that a lack of labor-market competition led to the shift of employment out of the Rust Belt over the post-war period.

7.2. Technology Adoption

Another proxy for productivity-enhancing investment activity is the rate of adoption of new 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. 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. Even though U.S. steel producers had ample opportunity to adopt these technologies, they nonetheless were laggards in adopting them (Adams and Brock, 1995; Adams and Dirlam, 1966; Lynn, 1981; Oster, 1982; Tiffany, 1988; Warren, 2001).[20]

The view that technology adoption in the U.S. steel industry was inefficiently low is in fact confirmed by the producers themselves. In its 1980 annual report, the American Iron and Steel Institute (representing the vertically integrated U.S. producers) admits that:

> Inadequate capital formation in any industry produces meager gains in productivity, upward pressure on prices, sluggish job creation, and faltering economic growth. These effects have been magnified in the steel industry. Inadequate capital formation ... has prevented adequate replacement and modernization of steelmaking facilities, thus hobbling the industry's productivity and efficiency (American Iron and Steel Institute, 1980).

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. In auto manufacturing, the sluggish rate of technology

[20]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." In continuous casting, adoption rates lagged as well. Only 15 percent of U.S. steel capacity by 1978 involved continuous casting, compared to 51 percent in Japan, 41 percent in Italy, 38 percent in Germany, and 28 percent in France.

adoption is widely acknowledged by industry historians and insiders, such as Adams and Brock (1995), Ingrassia (2011) and Vlasic (2011).

7.3. Cross Section of U.S. Cities

In this section, we look beneath the surface of the regional aggregates focused on until now, and consider the cross-section of Metropolitan Statistical Areas (MSAs) within the United States. What we find is that MSAs that had the lowest employment growth over the period 1950 to 2000 tended to be those that paid workers the highest wage premiums in 1950.

The data we use for this analysis are the decennial census micro data from IPUMS. The unit of geography is the 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 (determined by the Census Bureau), usually around 100,000 people. We also focus attention on 3-digit MSAs as defined by IPUMS, as these have changed definition relatively infrequently over time. We restrict the sample to all workers who report being primarily wage earners, as opposed to the self-employed, and only those employed in the private sector.[21]

We construct our measures of wage premiums as follows. As is standard, we assume that under competition, a worker's wage should be proportional to her human capital. Following the tradition of Mincer, we assume that a worker's human capital is a function of her 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

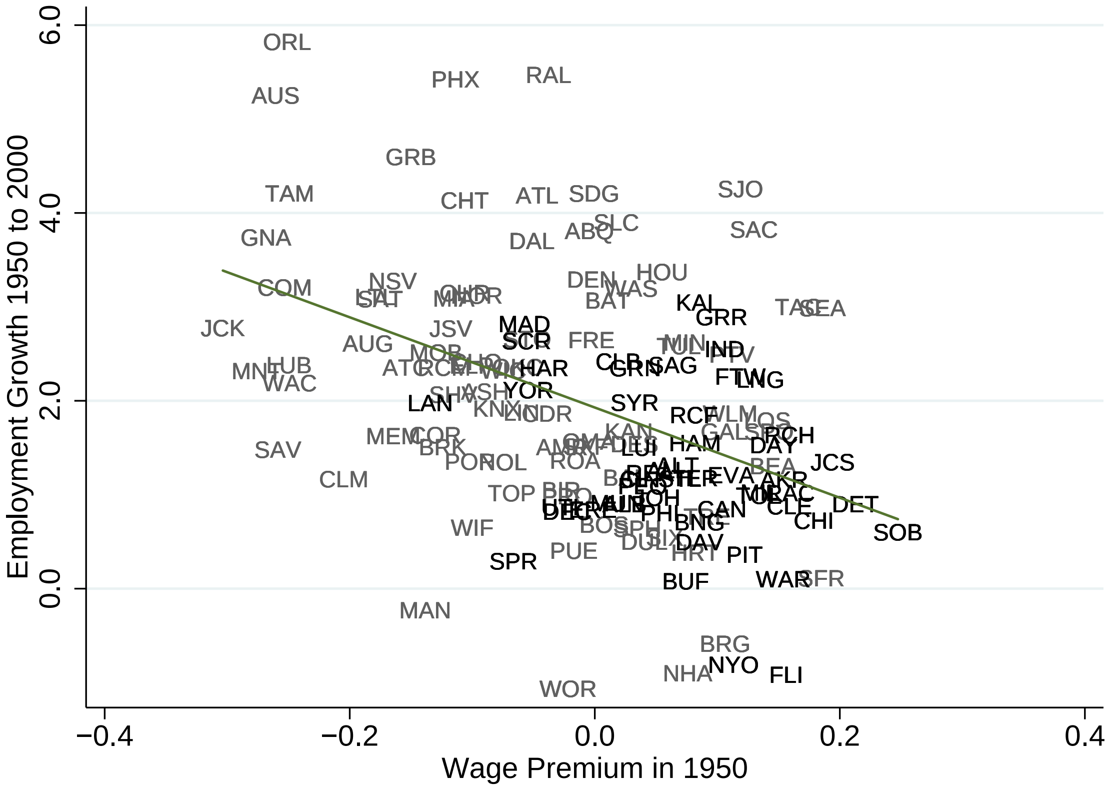
$$\log w_{i,m} = \alpha \cdot SCHOOL_{i,m} + \sum_{j=1}^{4} \beta_j \cdot EXPER_{i,m}^{j} + \sum_{m=1}^{M} D_m \cdot \pi_m + \varepsilon_{i,m} \tag{20}$$

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 (20) using the IPUMS micro data from 1950, and take the π_m terms as our measure of wage premiums by MSA.

Figure 8 shows the wage premium in 1950 (normalized to 0) plotted against the annualized growth

[21] Our results in this section corroborate the earlier results of Borjas and Ramey (2000), who document that *industries* paying the highest wage premiums in 1959 had the lowest employment growth through 1989. As many of the high-wage industries in their study (e.g. autos and steel) were concentrated in the high-wage MSAs of our study (e.g Detroit and Pittsburgh), we conclude that both sets of evidence are consistent with the basic prediction of the model.

Figure 8: Wage Premiums and Employment Growth across MSAs



in employment from 1950 to 2000. Rust Belt MSAs are displayed in black, while the rest are grey. 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-percent level. Among the MSAs with the highest 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.

8. Conclusion

This study asks why the Rust Belt's share of U.S. manufacturing employment declined so much since the end of World War II. To do so, we document four facts about the decline of the Rust Belt: (1) the slow and persistent decay of its employment share beginning in 1950, (2), its significant wage premium, (3), its relatively low labor productivity growth rate, and (4), a large change in all of these pattern beginning around the 1980s. To interpret these facts we develop a model economy that features limited competition in Rust Belt output markets and the conflicted labor relations between labor and management that characterized the region's industries for decades. In our model, the decline of the Rust Belt largely reflects the limited competition in labor markets and the resulting hold-up problem that reduced investment in the Rust Belt's main industries. In contrast, the increase in competition from abroad in the 1980s is inconsistent with the timing and magnitude of the Rust Belt's decline, most of which occurred already by 1980.

The substantial loss of Rust Belt employment raises the important question of why management and labor were not able to develop a more efficient way of sharing the rents in Rust Belt industries in order to stem employment loss. Our model predicts that the Rust Belt's employment losses would not have been as high had unions and firms been able to commit to long-term agreements. In reality, there are a number of unique factors characterizing Rust Belt labor relations that likely contributed to the inability of these players to commit in the long term. Specifically, as noted by former UAW President Bob King, labor conflict and mistrust characterized these industries for decades. Management often refused to cooperate with organized labor by providing them with information on profitability and industry health that was not accessible in public records. One possibility is that asymmetric information prevented the two parties from committing long term. Future research should further analyze the role of bargaining between workers and firms on innovation and productivity growth.

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Appendix (for Online Publication)

A. Data Appendix

Regional Cost-of-Living Differences, 1966

One potential explanation of the Rust Belt's wage premium we document in Section 3 is that the cost of living was higher in the Rust Belt than elsewhere in the United States. To address this hypothesis, we draw on the study of the U.S. Bureau of Labor Statistics (1967) that estimates costs of living across 39 U.S. metropolitan areas and 4 regional averages of urban areas not already included in one of the metropolitan areas. Their estimates are not exactly cost of living differences, since they adjust the expenditure basket in each region to take into consideration e.g. higher heating costs in colder areas. But they do attempt to capture the cost of an average budget for a family of "moderate living standards" in each city in question.

To compare average costs of living in the Rust Belt and elsewhere, we classify each city as being in the Rust Belt or in the rest of the country. The Rust Belt cities are: Buffalo, NY; Lancaster, PA; New York, NY; Philadelphia, PA; Pittsburgh, PA; Champaign-Urbana, IL; Chicago, IL; Cincinnati, OH; Cleveland, OH; Dayton, OH; Detroit, MI; Green Bay, WI; Indianapolis, IN; and Milwaukee, WI. The other cities are Boston, MA; Hartford, CT; Portland, ME; Cedar Rapids, IA, Kansas City, MO; Minneapolis, MN; St. Louis, MI; Wichita, KS; Atlanta, GA, Austin, TX; Baltimore, MD; Baton Rouge, LA; Dallas, TX; Durham, NC; Houston, TX; Nashville, TN; Orlando, FL; Washington, DC; Bakersfield, CA; Denver, CO; Honolulu, HI; Los Angeles, CA; San Diego, CA; San Francisco, CA; and Seattle, WA.

Table A.1 reports the averages across all 43 cities and non-metropolitan areas, compared to the U.S. average for all urban areas, which is normalized to 100. The Rust Belt has an average cost of 100.4, compared to 99.1 outside of the Rust Belt, for a difference of 1.3 percentage points. The *p*-value of this difference is 0.28, indicating that the difference is statistically insignificant at any conventional significance level. The second row excludes the four non-metropolitan areas. Not surprisingly, the average cost of living is higher in both regions, as larger urban areas tend to be more expensive. The difference is still 1.3 and statistically insignificant. The third row excludes Honolulu, the city with the highest cost of living, at 122. This brings the average cost of living down in the rest of the county, and raise the difference to 2.2 percentage points, though the *p*-value is 0.12. The last row excludes New York City, which has the second highest cost of living, at 111. New York City is in the Rust Belt, according to our definition, but not often thought of as a "Rust Belt" city. The Rust Belt is now 1.5 percentage points more expensive than the rest of the country, with a *p*-value of 0.22.

In summary, in none of the sample restrictions is the Rust Belt more than two percentage points more expensive than the rest of the country, and in all cases the difference is statistically insignificant. This casts substantial doubt on the hypothesis that workers in the Rust Belt earned higher wages in order to compensate them for higher costs of living.

Table A.1: Average Cost of Living in 1966, by U.S. City (U.S. = 100)

	Region		
	Rust Belt	Rest of Country	Difference
All cities	100.4	99.1	1.3
			(0.28)
Excluding non-metro areas	101.1	99.8	1.3
			(0.28)
Excluding Honolulu, HI	101.1	98.8	2.2
			(0.12)
Excluding New York, NY	100.3	98.8	1.5
			(0.22)

Note: The table reports the average cost of living in 1966 for cities in the Rust Belt and in the rest of the country, constructed by the BLS (1967). The overall average cost of living in urban areas is set to be 100. The right-hand column is the simple difference between the Rust Belt and the rest of the country, and below that, a p-value of the t-test that the means are the same. The first row includes 39 cities and averages for 4 non-metropolitan areas, in the northeast, north central, south and west. The second row includes only the 39 cities. The third row excludes Honolulu, and the last excludes Honolulu and New York City.

Average Wage Losses After Displacement

In order to compute average wage losses after displacement, we draw on the CPS Displaced Worker supplement from 1986. This is the earliest available CPS survey with supplemental questions for workers suffering a displacement from an employer. The main information of interest is whether the respondent was displaced from a job in the previous five years, and if so, what their wages were in the new job compared to the previous job. In our analysis, we restrict attention to hourly wage workers between 25 and 65 that lost their jobs due to a worker's plant or company closing or moving away. To measure wage loss from displacement, we compute the average weekly earnings at each worker's pre-displacement job divided by the average weekly earnings in their new job. We drop any workers with missing earnings or employment data, and the top and bottom one percent of wage changes. We then compare average wage loss for workers in the Rust Belt to workers in the rest of the country.

Table A.2: Percent Weekly Earnings Loss Among Displaced Workers, 1981-1986

	Region		
	Rust Belt	Rest of Country	Difference (p-value)
Mean	51.1	35.5	15.6
			(0.07)
Median	20.5	11.5	9.0
			(0.13)

Note: The table reports the mean and median percent weekly earnings loss for workers that were displaced from a job between 1981 and 1986, by region of the United States. The data comes from the Displaced Worker's Supplement to the 1986 CPS. Displacement means that the worker's plant or company shut down or moved. Wage loss is measured as the percent difference between the pre-displacement weekly earnings and the weekly earnings in 1986. The sample is restricted to workers that were full-time wage workers between age 25 and 65 at the time of their displacement, and who worked for a wage in 1986. The p-values are for a $t-$test of the difference in mean wage loss by region and a Wilcoxon rank-sum test of the equality of the distributions of wage loss by region.

Table A.2 presents our findings. When comparing mean wage loss, workers from both regions average very large wage losses, though these losses are higher in the Rust Belt. Displaced workers from the Rust Belt lose an average of 51.1 of their prior wages, while workers from the rest of the country lose 35.5 percent. The difference, of 15.6 percentage points, is statistically significant at seven percent level. Given how large the mean wage losses are, we compute also the median wage loss. Rust Belt workers lose a median of 20.5 percent of their prior wages, while workers from the rest of the country lose 11.5 percent. This difference, of 9 percent, has a p-value of 0.13.

One limitation of this analysis is that the sample size is fairly small. There are 84 displaced workers in our sample from the Rust Belt, and 229 from the rest of the country. The reason for the small sample size is that only a fraction of the CPS was asked the Displaced Worker questions, and of those, only a fraction were actually displaced. A second limitation is that the period in question is from 1981 to 1985, and this was largely after the large wage premiums we document in the Rust Belt had fallen.

B. Derivation of Cost Function

The optimality condition associated with the Bellman equation of on individual producer in sector $\ell \in \{r,s\}$ is:

$$\frac{\partial C(x,Z,z)}{\partial x}\frac{P}{z} = \delta\Big\{(1-\beta)\frac{\partial \pi_\ell(Z',z')}{\partial z'} + \frac{\partial C(x',Z',z')}{\partial x'}\frac{z''}{(z')^2}P' + \frac{\partial C(x',Z',z')}{\partial z'}P'\Big\}. \tag{21}$$

Next, we need to show that the optimal policy x is homogeneous of degree 0 with respect to *all* productivities. A sufficient condition is to show that both sides of the optimality condition are homogeneous of the *same* degree with respect to the productivities since proportional changes in the productivities cancel out in that case. Since

$$C(x,Z,z) = \alpha x^\gamma \frac{z^{\rho-1}}{D(Z)}$$

and

$$D(Z) = \left(\lambda\left[Z_R^{\rho-1} + Z_R^{*\rho-1}\right]^{\frac{1-\sigma}{1-\rho}} + (1-\lambda)\left[Z_S^{\rho-1} + Z_S^{*\rho-1}\right]^{\frac{1-\sigma}{1-\rho}}\right)^{\frac{2-\rho}{1-\sigma}} \tag{22}$$

in any symmetric equilibrium, we can show that the derivative of the cost function with respect to the policy x is homogeneous of degree 1. Moreover, the derivative with respect to the state z is homogenous of degree 0.

Finally, the profit function of a producer in sector ℓ is:

$$\pi_\ell(Z,z) = \rho^{1-\rho}(\rho-1)^{\rho-2}z^{\rho-1}\left(P_\ell^{\rho-\sigma}P^{\sigma-1} + \tau^{1-\rho}w^*P_\ell^{*\rho-\sigma}P^{*\sigma-1}\right)$$

Clearly then, the derivative of $\pi_\ell(Z,z)$ with respect to z is homogeneous of degree -1.

Inspection of the price indices in section 5.6 reveals that the aggregate price index is homogeneous of degree -1 with respect to all productivities. Clearly then, both sides of the optimality condition are homogeneous of degree -1. As a result, the optimal innovation rate x is scale independent and hence homogeneous of degree 0 with respect to the productivities. Since only relative productivities matter, we normalize the productivity of a Rest of the Country producer to unity ($Z_s = 1$) each period.

The denominator of the cost function in equation (22) is one of many with the required degree of homogeneity guaranteeing that the policy x is homogeneous of degree zero with respect to all productivities. However, this particular functional form for the denominator has an additional property that we believe is useful and noteworthy in its own right. In the special case of the economy with no union hold-up ($\beta = 0$), free trade ($\tau = 1$), and no comparative advantage $\Big(\frac{Z_r^*}{Z_r} =$

$\frac{Z_s^*}{Z_s} = \mu)$, the policy x does *not* depend on the aggregate endogenous state Z and an individual firm will grow at a constant rate regardless of its own productivity z. Put differently, the economy is on a balanced growth path.

Since the price indices are equalized across countries whenever $\tau = 1$ and countries are only differentiated by the absolute advantage (parameterized by μ), the trade balance condition (15) can be simplified to:

$$w^* = \mu^{\frac{\rho-1}{\rho}} \tag{23}$$

After substituting the expression for the foreign wage into the optimality condition (21) and exploiting the fact that $P = P^*$ and $P_\ell = P_\ell^*$ for $\ell \in \{r, s\}$, the endogenous state variables (i.e. the idiosyncratic and aggregate productivities) drop out and the optimal innovation rate is given by equation (19), which is only a function of the parameters and the extent of foreign's *absolute* advantage μ.

C. Appendix Tables and Figures

Table C.1: Relative Wages of Rust Belt Workers

	Relative Wages	
	1950	2000
Manufacturing workers	1.13	1.02
All workers	1.17	1.01
Full-time workers	1.17	1.04
All Workers + more detailed race controls	1.16	1.03
All Workers + more detailed race & schooling controls	1.14	1.00

Note: Relative Wages are defined as one plus the coefficient in a Mincer-type log-wage regression of a dummy variable taking the value of 1 for workers living in the Rust Belt, and 0 otherwise, interacted with years 1950 and 2000. The controls in the regression are educational attainment dummies, a quartic polynomial in potential experience, and dummies for full-time status, immigrant status, nonwhite status, sex, year, and year X Rust Belt interaction terms.

Figure C.1: Productivity Growth Rate in Model

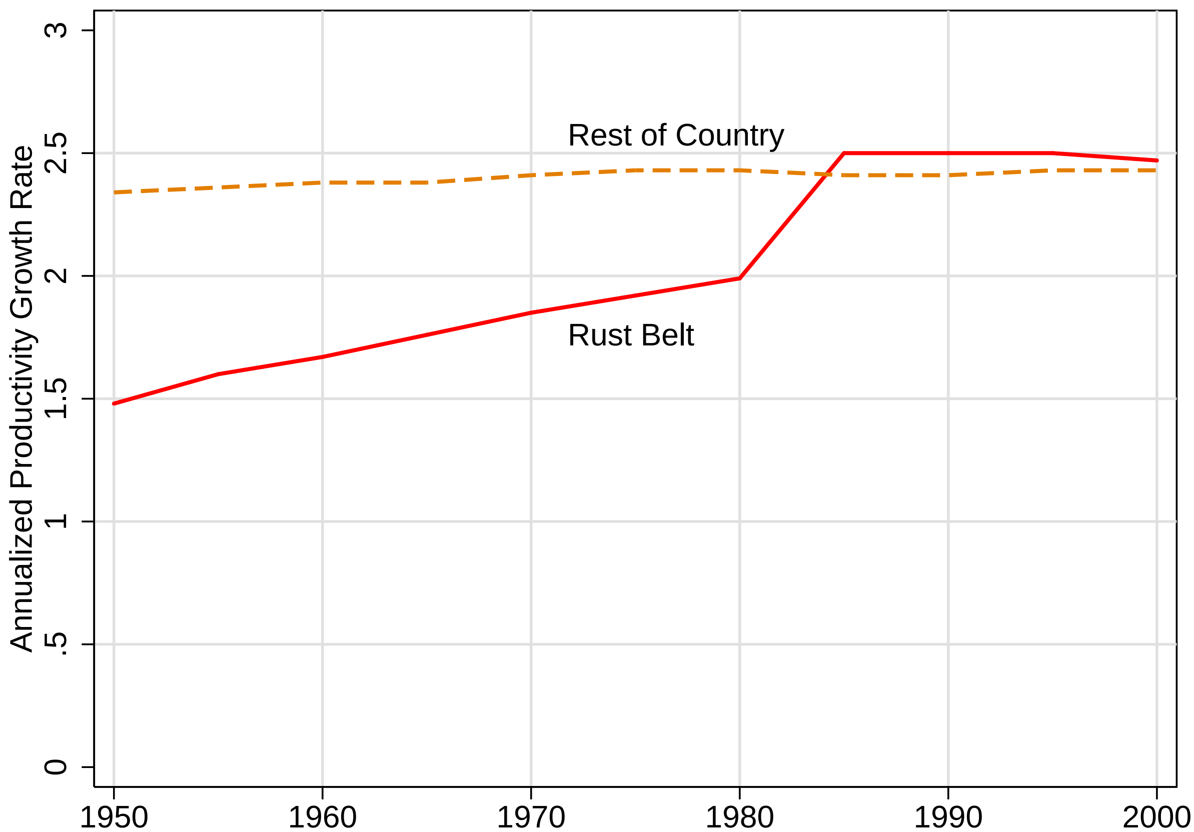

Table C.2: Labor Productivity Growth in Rust Belt Industries, Expanded Definition

	Annualized Growth Rate, %		
	1958-1985	1986-1997	1958-1997
Blast furnaces, steelworks, mills	0.9	7.6	2.8
Construction and material handling machines	0.9	2.1	1.3
Engines and turbines	2.3	2.8	2.5
Farm machinery and equipment	1.7	2.3	1.9
Iron and steel foundries	1.5	2.3	1.7
Leather products, except footwear	2.3	1.4	2.0
Leather tanning and finishing	0.7	4.5	1.8
Machinery, except electrical, n.e.c	1.0	1.5	1.2
Metal forgings and stampings	1.5	2.8	1.9
Metalworking machinery	0.9	3.5	1.6
Misc. fabricated metal products	1.1	1.7	1.3
Misc. paper and pulp products	2.6	1.9	2.4
Misc. plastics products	3.2	2.8	3.1
Motor vehicles and motor vehicle equipment	2.5	3.8	2.9
Office and accounting machines	4.8	−1.3	3.1
Other primary metal industries	−1.9	7.5	0.8
Other rubber products, plastics, footwear & belting	2.7	2.0	2.5
Paints, varnishes, and related products	3.2	2.2	2.9
Photographic equipment and supplies	4.8	5.1	4.9
Pottery and related products	0.7	−1.0	0.2
Railroad locomotives and equipment	1.6	3.0	2.0
Screw machine products	1.3	1.1	1.2
Sugar and confectionary products	3.4	3.1	3.3
Rust Belt, Expanded Definition weighted average	2.1	2.9	2.3
Manufacturing weighted average	2.6	3.2	2.8

Note: Rust Belt Industries, Expanded Definition are defined as industries whose employment shares in the Rust Belt region are more than *one-half* standard deviation above than the industry mean. Labor Productivity Growth is measured as the growth rate of real value added per worker. Rust Belt weighted average is the employment-weighted average productivity growth rate for Rust Belt industries under the expanded definition. Manufacturing weighted average is the employment-weighted average growth over all manufacturing industries. Source: Author's calculations using NBER CES productivity database, U.S. census data from IPUMS, and the BLS.