Competitive Pressure and the Decline of the Rust Belt: A Macroeconomic Analysis

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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 in its labor and output markets. We formalize this thesis in a two-region dynamic general equilibrium model, in which productivity growth and regional employment shares are determined by the extent of competition. Quantitatively, the model accounts for much of the large secular decline in the Rust Belt's employment share before the 1980s, and the relative stabilization of the Rust Belt since then, as competitive pressure increased.

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1. Introduction

No region of the United States fared worse over the postwar period than the "Rust Belt," the heavy-manufacturing region bordering the Great Lakes. We document that 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 that its share of aggregate employment dropped by a similar magnitude. In addition, we document that wages in the Rust Belt were higher on average than in the rest of the country, and that labor productivity growth in most of the Rust Belt's industries was lower than average.[1]

We use these facts to develop a new theory of the Rust Belt's decline. Our theory focuses on the lack of competitive pressure in the Rust Belt's labor and output markets. In practice, lack of competition was a salient feature of the region's postwar economy. Output markets in many of the region's industries were dominated by oligopolies that faced little competition for decades after the war. Similarly, powerful labor unions controlled the Rust Belt's labor markets and used their bargaining power to obtain higher payments from their employers.

Our theory has two parts. The first part formalizes the idea that a lack of competition in labor and output markets depressed the firms' incentives to innovate and thereby raise productivity. This part builds on a growing literature that connects lack of competitive pressure to low productivity (see e.g. Acemoglu, Akcigit, Bloom, and Kerr, 2013; Aghion, Bloom, Blundell, Griffith, and Howitt, 2005; Schmitz, 2005; Holmes and Schmitz, 2010; Syverson, 2011). The second part links depressed productivity growth to the decline of the region's employment share. This channel builds on models of structural change, which connect sectoral productivity growth to employment dynamics (see e.g. Ngai and Pissarides, 2007; Buera and Kaboski, 2008; Herrendorf, Rogerson, and Valentinyi, 2014).

We combine these two parts in a dynamic general equilibrium model in which the extent of competition in output and labor markets determines productivity growth, wages, and regional employment shares. In labor markets, regional differences in competitive pressure are governed by the presence of a labor union in the Rust Belt. While firms bear the full cost of innovation, they must bargain with the union over profits, which are determined in part by the firm's current innovation decision. This leads to a "hold up" problem in the Rust Belt that discourages innovation and lowers productivity growth. In output markets, since Rust Belt producers face less competitive pressure from close competitors, they can earn rents even with little or no innovation, which dulls their incentive to innovate, all else equal.

Regional employment shares evolve endogenously and are driven by relative productivity growth.

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[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.

Since goods are gross substitutes in production, demand shifts toward goods from the region whose productivity growth is highest. As a result, the employment share of the Rust Belt declines as long as its productivity growth is lower than that of producers in the rest of the country.

We use the model to quantify how much of the Rust Belt's employment share decline can be accounted for by our theory. We use estimated markups and wage premia to discipline differences in competitive pressure between the Rust Belt and the rest of the country. We then calculate the equilibrium of the model from 1950 through 2000, in which innovation, productivity growth, and employment shares endogenously evolve in the two regions. The model predicts a large secular decline in the Rust Belt's employment share of about 11 percentage points, which accounts for around two-thirds of the actual 17 percentage-point decline. The model also predicts that productivity growth in the Rust Belt is lower than in the rest of the country, as in the data.

There is considerable evidence that competitive pressure in output and labor markets picked up around the 1980s. We exploit this change to test our theory. When we feed this rise in competition into our model, it predicts a falling wage premium, an increase in productivity growth, and a slowdown in the Rust Belt's employment share decline. In the data, the Rust Belt's wage premium did indeed fall in the 1980s, its productivity growth did increase in most of its industries, and its decline did slow in the 1980s.

We conclude by presenting additional evidence supporting the theory's mechanism and predictions. First, we show that across Metropolitan Statistical Areas (MSAs) of the United States, MSAs that paid the highest wage premia in 1950 tended to have the lowest employment growth from 1950 to 2000. To the extent that wage premia in 1950 reflect non-competitive labor markets, this finding provides further disaggregated evidence that a lack of competitive pressure in labor markets played a role in regional employment changes. Second, 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 innovation 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 introduces a model extension with forward-looking unions. Section 8 presents additional supporting evidence and Section 9 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 (2012), 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.

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 (2011) 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. Acemoglu and Robinson (2013) discuss the relationship between competition, innovation and productivity at the national level.

From a modeling perspective, our work 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), and Peters (2013). By combining an endogenous growth model and a union bargaining problem, we more heavily emphasize the interaction between competition in labor and output markets than the previous literature. A common theme, however, is that more competitive output markets encourage incumbent firms to innovate more aggressively in order to maintain a productivity advantage over potential entrants (Aghion, Akcigit, and Howitt, 2014). 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.

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

3. Decline of the Rust Belt: The Facts

In this section we document a set of facts characterizing the Rust Belt's decline. First, the Rust Belt's share of aggregate and manufacturing employment declined secularly over the postwar period. Second, wages in the Rust Belt were higher than in the rest of the country. Third, labor productivity growth in industries located predominantly in the Rust Belt was lower than average. Fourth, all these empirical patterns changed significantly in the 1980s: the Rust Belt's employment share decline slowed, its wage premia fell, and its labor productivity growth picked up.

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.

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[2] 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 (2012), is the link between inequality and unionization, which is absent from the current paper.

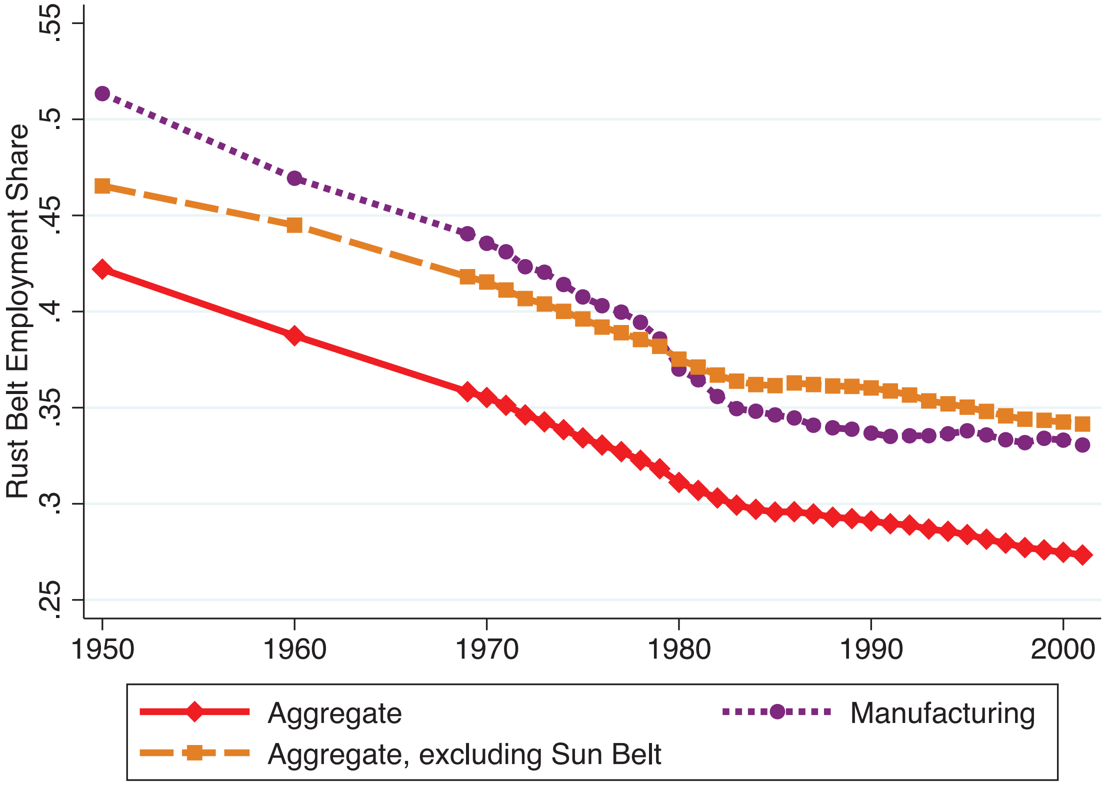

Figure 1: The Rust Belt's Employment Share

Fact 1: Declining Employment Share

The first fact is that the Rust Belt's share of employment decreased secularly over the postwar period. Figure 1 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.[3]

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 1 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*

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[3] 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.

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 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 1 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.[4]

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

Fact 2: High Wages in the Rust Belt

The second fact 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 2 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 5.) 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

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[4] 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.

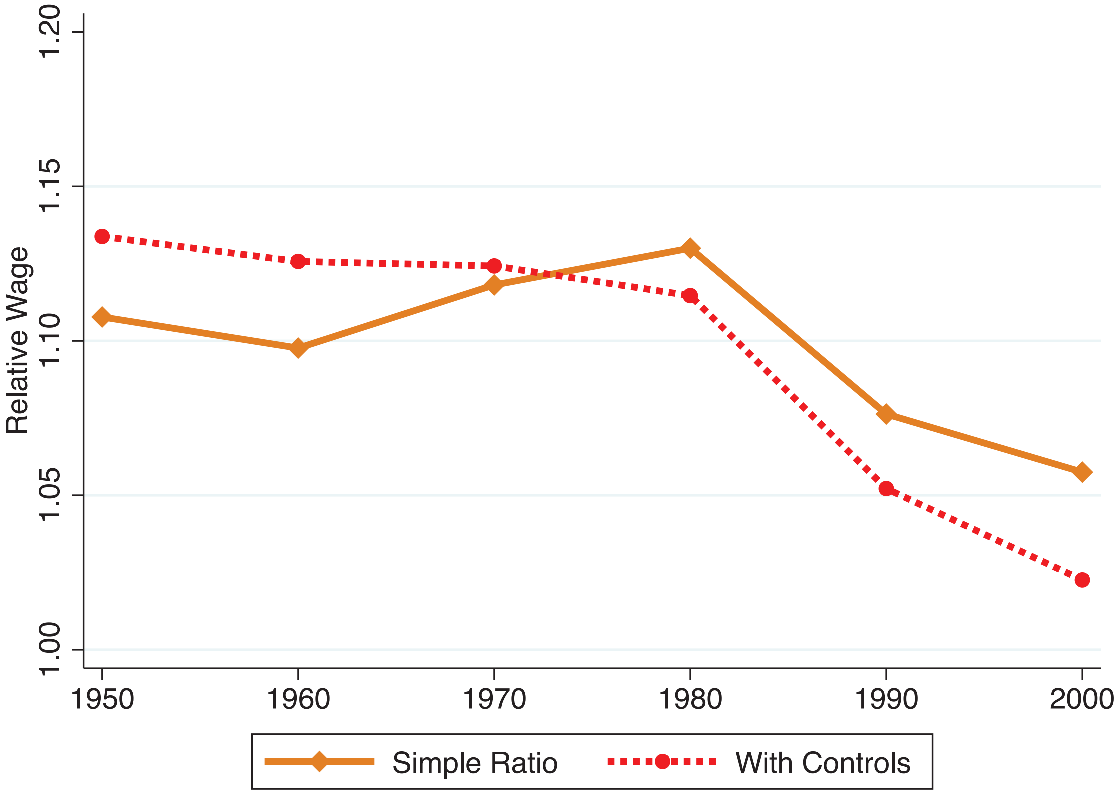

Figure 2: Relative Wages of Rust Belt Workers

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.

Fact 3: Low Productivity Growth in Rust Belt Industries

The third 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 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,

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.

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).[5]

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

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[5] In Appendix Table 6 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/.

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.[6]

Fact 4: Changes of the 1980s

The three Rust Belt facts described above - the substantial decline in its employment share, its wage premium, and its low productivity growth - changed significantly in the 1980s. Figure 1 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 2 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 5 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 Belt industries in the 1980s, rising from an average of 4.8 percent to 7.7 percent per year. Appendix Table 6 shows that productivity increases occurred, on average, under a broader definition of Rust Belt industries.

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[6] A second potential limitation of the productivity evidence of Table 1 is that it compares Rust Belt industries to other industries that may have differed in potential for productivity growth. When comparing the U.S. steel and auto industries to their counterparts abroad, however, previous studies have found much lower productivity growth in the U.S. than in Japan and Europe over this period; see Fuss and Waverman (1991) and Norsworthy and Malmquist (1983) on the auto industry and Lieberman and Johnson (1999) on steel industry.

4. Lack of Competition in the Rust Belt

This section presents evidence that competitive pressure in output and labor markets in the Rust Belt was low throughout much of the postwar period, particularly before the 1980s. Then, starting around the 1980s, competitive pressure increased, as output markets drew new competition from home and abroad, and the influence of unions declined. We use these historical narratives on labor and product market competition, along with data on wage premia and markups, to support our thesis that competition increased significantly around the 1980s.[7]

4.1. Lack of Competitive Pressure in Labor Markets

The Rust Belt was the most unionized region of the United States over the postwar period. A detailed study from 1974, for example, showed that four of the five most unionized states were in the Rust Belt (Michigan, West Virginia, New York and Pennsylvania), as well as seven of the top ten (U.S. Bureau of Labor Statistics, 1975). The Rust Belt was also home to two of the largest unions in the country: the United Steelworkers (USW) and United Auto Workers (UAW), which were acknowledged to be among the most powerful in the country (Goldfield, 1987).

Many studies conclude that these unions, and others like them in the Rust Belt, used the threat of strikes to obtain higher payments from firms. In the steel industry, in each of the ten years following WWII, union steel workers demanded wage and benefit increases and specified a strike date in case the union was not satisfied with their employer's response (Hogan, 1971, p. 1611-1645). Not surprisingly then, steel workers in this period earned substantially higher than average wages; Tiffany (1988) reports that hourly earnings for steel workers in 1959 were more than 40 percent higher than the manufacturing average in the United States, which he interprets as rents (p. 178). For the auto industry, Ingrassia (2011) and Vlasic (2011) describe numerous concessions obtained by workers under threat of strike, including above-average wages and non-wage benefits.[8]

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[7] Several factors may have led competitive pressure in the Rust Belt to be low at the end of the World War II. New Deal laws, such as the National Industrial Recovery Act, facilitated collusion in the 1930s by some of the Rust Belt's most prevalent sectors, such as steel. While later outlawed, much of the collusive behavior may have persisted for years after the New Deal. Similarly, during the war, wartime economic planning suppressed normal market competitive forces. See Cole and Ohanian (2004) for a discussion of anti-competitive policies of the 1930s, and see McGrattan and Ohanian (2010) for a discussion regarding the World War II economy.

[8] In 1950, the UAW and GM negotiated the "Treaty of Detroit," a five year contract that was designed to stop strikes and bring peace to auto labor relations, and that was also presumed to serve as a model for other industries. This treaty, however, did not solve labor conflict, as holdup continued after that, with major strikes, and threats of strikes, in the steel and auto industries. In a 2010 speech, UAW President Bob King acknowledged the persistent and inefficient labor relations between the UAW and the auto industry that persisted in the 20th century: "The 20th-century UAW joined with the companies in a mindset that it was the company's job to worry about profits, and the union's job to worry about getting the workers their fair share...The 20th-century UAW fell into a pattern with our employers where we saw each other as adversaries rather than partners."

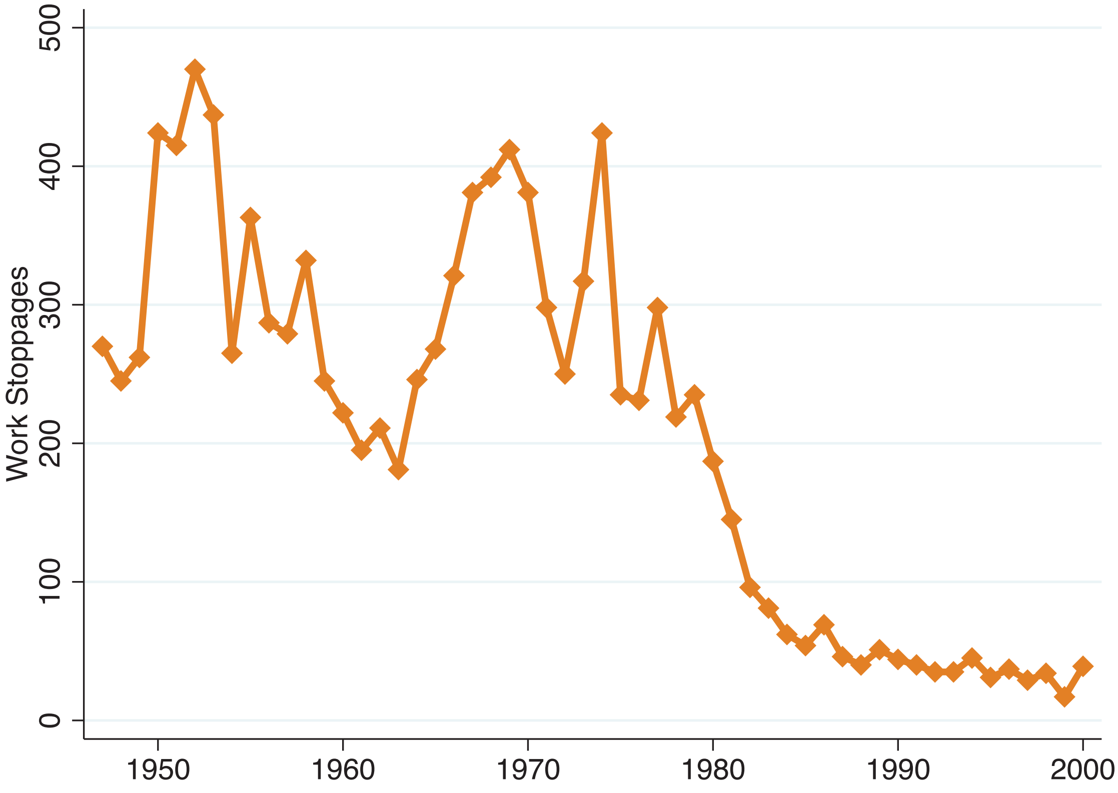

Figure 3: Work Stoppages Affecting More Than One Thousand Workers

Figure 3 plots the number of work stoppages involving more than one thousand workers each year, as reported by the BLS, which we interpret as a measure of union bargaining power. Two features of the graph are noteworthy. First, for several decades after the end of the war, strike activity was substantial in the United States, averaging 300 strikes per year involving more than one thousand workers. While these data are not reported by region, there is good reason to believe the majority of these strikes occurred in the Rust Belt, since most of the most powerful unions (such as the USW and UAW had extensive operations there. As one example, the famous steel strike of 1959 idled more roughly 500,000 steel workers in mills located mostly in Illinois, Ohio and Pennsylvania (Tiffany, 1988). The auto industry had major strikes at Ford in 1967, Chrysler in 1968 and General Motors in 1970, and these strikes idled plants located almost exclusively in the Rust Belt.

The second noteworthy feature of Figure 3 is that strike activity dropped substantially around 1980 and stayed a much lower level. Afterwards, the number of strikes affecting more than one thousand workers averaged just 50 per year. This sharp drop in work stoppages relates closely to a previously documented decline in union organizing activity starting around 1980 (Farber and Western, 2001; Dinlersoz, Greenwood, and Hyatt, 2014). Two commonly cited explanations for the decline in union power include the policy stance towards unions advanced under the Reagan administration (Freeman and Nickell, 1988) and an increase in competitive forces, discussed by Reder (1988) and Farber and Western (2001). In either case, there is considerable agreement that labor unions became significantly weaker around the early 1980s.

4.2. Lack of Competition in Output Markets

This section summarizes competitive pressure among Rust Belt producers, and how this pressure changed over time, including the available evidence on changes in markups over time. Since there is very limited evidence on how industry markups change over time, however, we supplement the markup estimates with the following historical narrative that describes broader changes in competitive pressure among Rust Belt producers. The most prominent Rust Belt industries were dominated by just a handful of firms in the decades after WWII. The three largest steel producers – U.S. Steel, Bethlehem Steel, and National Steel – accounted for nearly all U.S. market share after World War II and had at least half of domestic capacity through 1980 (Crandall, 1981; Tiffany, 1988). The "Big Three" car companies – General Motors, Ford and Chrysler – accounted for 90 percent of automobile sales in the United States in 1958, and at least 75 percent until around 1980 (Klier, 2009). Rubber tire production was similarly concentrated by their own big four – Goodyear, Firestone, U.S. Rubber, and Goodrich – which controlled at least 90 percent of the market from 1950 to 1970.

In each of these industries, it is generally recognized that firms faced little competitive pressure and had considerable market power. Adams and Brock (1995, p. 94) describe the big Steel producers as having had "virtually unchallenged control of a continent-size market," which led to a "well-honed system of price leadership and follower-ship" with U.S. Steel as the clear leader in price setting. Similarly, Hudson and Sadler (1989) state that: "in 1948 the industry (...) [began] a system whereby all firms automatically followed U.S. Steel's lead in pricing." Ingrassia (2011, p. 29) describes the automobile industry as being a "model of corporate oligopoly" throughout the 1950s, 1960s and 1970s, with General Motors as price leader.

The U.S. steel, auto, and rubber tire manufacturers were accused many times of explicit collusion. In 1959, the Federal Trade Commission (FTC) charged fifteen rubber manufacturers with agreeing on common list prices and discounting policies (French, 1991). Tiffany (1988) describes similar instances in the steel industry, and on several occasions Congress invited senior management of *Big Steel* to explain their lack of competition in pricing. By 1963, the Senate Antitrust and Monopoly Committee concluded that there was little, if any, price competition in steel and auto industries, and recommended that General Motors be broken up into competing firms. Similarly, the U.S. Justice Department charged Ford and General Motors with collusion and the Big Three with conspiring to eliminate competition (Adams and Brock, 1995, p. 87)

There is substantial evidence that competitive product market pressure in the Rust Belt increased in the 1970s and particularly in the 1980s, as new firms entered, both foreign and domestic, and imports increased. Concentration ratios fell substantially in steel, auto and rubber industries. Market share for auto producers fell from around 90 percent to less than 50 percent, and market share declined similarly for Rust Belt steel and rubber producers (Tiffany, 1988; French, 1991). Estimates of markups also declined as competition increased. Collard-Wexler and De Loecker (2015) use detailed producer-level data to estimate that, in the US steel industry, markups fell by around 50 percent over the last forty years. They attribute the falling markups to rising competition.[9] Several industry studies also find increased competitive pressure from imports starting around 1980, such as Schmitz (2005)'s study of the U.S. iron ore industry, and Dunne, Klimek, and Schmitz (2010)'s study of the U.S. cement industry.

Economic policy changes also fostered greater competitive pressure on Rust Belt industries. McGrattan (2012) shows that policies that impeded foreign direct investment (FDI) in the 1960s and 1970s changed considerably in the mid-late 1970s. In particular, three policies that reduced FDI were explicitly or implicitly dissolved: interest equalization taxes on FDI, which had significantly increased tax rates on FDI, extraterritorial application of U.S. laws, which had permitted the U.S. to prosecute foreign companies for antitrust violations even if the alleged acts occurred outside the U.S., and national security laws, which had permitted the U.S. to seize foreign assets.

5. Model

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 lack of competition in the Rust Belt's output markets and the persistent conflicted labor relations in its labor markets. 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.

5.1. Households and Regions

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

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

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[9] Measures of markups consistently estimated over time are not available for many other industries. Nevertheless, estimates for the auto industry also show lower markups. Berndt, Friedlaender, and Chiang (1990) estimate markups for Ford, GM, and Chrysler between 1959 and 1983 averaging 21 percent, and just 13 percent afterwards.

where their discount factor δ satisfies $\delta \in (0,1)$. The households are endowed with one unit of labor each period and they supply their unit endowment inelastically to the market. Labor input is the numeraire, and hence the wage is normalized to one.

There is a continuum of intermediate goods, indexed by j, which are combined to produce a final good. The final good is either consumed or used in the innovation process. The production function for the final good is given by

$$Y_t = \left(\int_0^1 q_t(j)^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}} \tag{2}$$

where $q_t(j)$ is the quantity of intermediate j used in production of the final good, and σ is the elasticity of substitution between any two varieties. We assume that $\sigma > 1$, meaning that any two varieties are gross substitutes.

The households pool workers' labor earnings plus profits from the firms, and spend all their income on the final good. Formally, the households' budget constraint is

$$P_t \cdot C_t = 1 + R_t + \int_0^1 \Pi_t(j) dj \tag{3}$$

where P_t is the price of the final good, C_t is the quantity of the final good purchased for consumption, $1 + R_t$ is the labor earnings of all workers plus the rents earned by workers in the Rust Belt (explained below), and $\Pi_t(j)$ are net profits earned by intermediate firm j (also explained below).

We model the two regions of the economy as two disjoint intervals on $[0,1]$. This simplification allows for tractability, while still capturing the feature that goods in the two regions are imperfect substitutes for one another. Intermediates $j \in [0, \lambda)$ are produced in the Rust Belt, and intermediates $j \in [\lambda, 1]$ are produced in the Rest of the Country (ROC). The two regions differ in the nature of competition in their respective labor and output markets, as we describe in detail below. We use subscripts R for the Rust Belt and S for the Rest of the Country.

5.2. Intermediate Production and Innovation

Each intermediate can be produced by either an incumbent firm or a "competitive fringe" (or potential entrant). Here we focus on the incumbent, and detail the competitive fringe later.

Each period consists of two stages: innovation and production. In the innovation stage, the incumbent begins with productivity $z_{j,t}$ and chooses $x_{j,t}$, the percentage by which it improves its productivity. Upgrading productivity by $x_{j,t}$ requires an investment $I(x_{j,t}, Z_t)$, paid in units of the final good, where $Z_t \equiv \{z_{i,t}\}_{i=0}^1$ denotes the set of productivity levels of all producers, and $I(x_{j,t}, Z_t)$ is convex in $x_{j,t}$. The productivity upgrade is irreversible once it has been made and therefore the investment is sunk. After innovation, the incumbent's productivity is raised to $z_{j,t}(1+x_{j,t})$ and it produces intermediate j with the technology

$$y_{j,t} = z_{j,t}(1+x_{j,t})\ell_{j,t}, \tag{4}$$

where $y_{j,t}$ and $\ell_{j,t}$ represent output and labor input, respectively.[10]

At the production stage, incumbent firms decide how much labor to hire and what price to charge, given their technology and demand for their output. In both regions, the incumbents engage in Bertrand price competition with the competitive fringe. Because of the CES production function (2), incumbents also compete with other varieties, which are gross substitutes. Hence incumbents face a downward-sloping demand for their good. We describe their production-stage problem in detail below.

5.3. Extent of Competition

The key difference between the two regions is that the Rust Belt's labor and output markets feature less competitive pressure. We model the extent of competitive pressure in each period using two parameters: β_t and μ_t, satisfying $\beta_t \in [0,1]$ and $\mu_t \in [0,1]$. These parameters represent "distortions" to competition in the Rust Belt's labor markets and output markets, respectively. For simplicity we assume no distortions to competition in the Rest of the Country.

We model the Rust Belt's labor market as an atemporal Nash labor bargaining problem between a union and the incumbents, in which bargaining takes place after the innovation decision. This specification provides a simple way of capturing the persistent holdup problem that characterized Rust Belt labor relations for decades, as we discussed in Section 4. There is a representative labor union in each Rust Belt industry that is the sole supplier of labor services. In exchange for supplying labor, Rust Belt workers receive the standard competitive wage plus a union rent, R_t. The rent R_t is determined through Nash bargaining between the union and firm over period-t profits. The parameter β_t is the union's bargaining weight, and hence its share of period-t profits.[11]

Bargaining takes place at the end of the production stage, and in particular after the incumbent

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[10] In reality, innovation often takes the form of a new technology embodied in capital equipment. Examples from the Rust Belt during our time period include the continuous casting process for making steel, which required steel makers to install new casting machinery. For simplicity, we abstract from capital and treat innovation as a purely labor-augmenting productivity. What is key for our purposes is that the innovation is sunk and can be held up by the union.

[11] Since pay in the Rust Belt is above the competitive wage, there is rationing of Rust-Belt jobs. We assume that Rust-Belt job are randomly allocated. In reality, the actual allocation of union jobs was not random and often reflected family ties or other connections. In some instances, immigrants or members of minority groups were given lower preference. We abstract from these complications for simplicity since the distribution of union rents across members of the household is not crucial for our theory.

Rust Belt producer has made its innovation decision. This timing allows the model to capture the hold-up problem that characterized a number of Rust Belt industries in reality. In short, the hold-up problem arises in the model because the firm bears all the innovation costs, but then must split the profits with the union.[12]

In output markets, the extent of competition is governed by μ_t. The incumbent firm in each industry j competes with a competitive fringe, which may also produce the same variety. The productivity of the competitive fringe differs by region. In the Rest of the Country, the fringe can produce with productivity $\phi z_{j,t}$, with $\phi \in [0,1]$, where ϕ captures the potential for catch-up by the fringe. In the Rust Belt, the fringe can produce with productivity $(1-\mu_t)\phi z_{j,t}$ where μ_t stands for the additional degree of market power the firm has in output markets. The higher is μ_t, the less productive is the fringe in the Rust Belt, and the lower is the competitive pressure put on the incumbent.

Parameters β_t and μ_t evolve exogenously over time, and (for now) we assume all agents in the economy have perfect foresight.

5.4. Optimal Production and Pricing

We first consider the static problem that an incumbent firm faces in the production stage. In this stage, the innovation decision has already been made, and the incumbent's productivity has been determined. The firm's problem is to choose a price and quantity to maximize its current-period profits.

Consider a firm in the Rest of the Country entering the period with productivity z_S who has chosen a productivity increase x_S. We drop the t and, whenever possible, the j subscripts, and focus on symmetric equilibria. Assume, in addition, that all the other firms in the region have productivity $\tilde{z}_S$ and have chosen upgrade $\tilde{x}_S$ (which could be equal to z_S and x_S, and will be in equilibrium). Finally, assume that all Rust Belt producers start with productivity $\tilde{z}_R$ and have chosen $\tilde{x}_R$.[13] To keep the notation tidy, we define $Z_S \equiv (z_S, \tilde{z}_S, \tilde{z}_R)$ and $X_S \equiv (x_S, \tilde{x}_S, \tilde{x}_R)$.

Firms in the Rest of the Country seek to maximize current-period profits:

$$\Pi_S(Z_S, X_S; \beta, \mu) = \max_{p_S,\, \ell_S} \Big\{ p_S y_S - \ell_S \Big\}, \tag{5}$$

subject to $y_S = z_S[1+x_S]\ell_S$ and $y_S = E \cdot P^{\sigma-1} \cdot p_S^{-\sigma}$, which are the production function and standard demand function, respectively, when the final good is produced using a CES technology. E and P

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[12] In Section 7, we consider a model extension with a forward-looking union, and show that the predictions of that model are quantitatively similar to those of the current model.

[13] A sufficient condition for symmetry is $z_R = \tilde{z}_R$ and $z_S = \tilde{z}_S$.

represent total spending on all goods and the aggregate price index, respectively:

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

Optimal pricing falls into one of two cases. If innovation in equilibrium is sufficiently low, i.e. $x_S \leq \frac{\sigma\phi}{(\sigma-1)} - 1$, the incumbent chooses a limit price of $p_S = \frac{1}{\phi z_S}$ such that potential entrants weakly prefer not to enter the industry. Alternatively, for $x_S > \frac{\sigma\phi}{(\sigma-1)} - 1$, the firm can set a standard Dixit-Stiglitz monopolist markup of $p_S = \frac{\sigma}{\sigma-1} z_S(1+x_S)$ without triggering entry.

Now consider a Rust Belt firm that enters the period with productivity z_R and has chosen the innovation level x_R, while all other Rust Belt producers start with productivity $\tilde{z}_R$ and innovation $\tilde{x}_R$. Similarly, assume that all Rest of the Country producers enter with productivity $\tilde{z}_S$ and have chosen innovation $\tilde{x}_S$. Let us define $Z_R \equiv (z_R, \tilde{z}_R, \tilde{z}_S)$ and $X_R \equiv (x_R, \tilde{x}_R, \tilde{x}_S)$. Period profits of the Rust Belt are given by

$$\Pi_R(Z_R, X_R; \beta, \mu) = \max_{p_R,\, \ell_R} \Big\{ p_R y_R - \ell_R \Big\}, \tag{6}$$

subject to $y_R = z_R[1+x_R]\ell_R$ and $y_R = X \cdot P^{\sigma-1} \cdot p_R^{-\sigma}$. Like in the Rest of the Country, the optimal pricing strategy of the Rust Belt incumbents has two cases. When investment is sufficiently low in equilibrium, i.e. $x_R \leq \frac{\sigma\phi(1-\mu)}{(\sigma-1)} - 1$, they limit price the fringe with price $p_R = \frac{1}{(1-\mu)\phi z_R}$. In contrast, for sufficiently high levels of x_R, they set a standard markup of $p_R = \frac{\sigma}{\sigma-1} z_R(1+x_R)$.

5.5. Optimal Innovation

We now consider the dynamic problem that an incumbent firm faces in the innovation stage. In this stage, firms choose how much to innovate today to maximize the expected present discounted value of their share of profits.

The Bellman equation that describes a producer in the Rest of the Country is:

$$V_S(Z_S; \beta, \mu, t) = \max_{x_S} \Big\{ \Pi_S(Z_S, X_S; \beta, \mu) - I(x_S, Z_S) + \delta V_S\big(Z_S'; \beta', \mu', t+1\big) \Big\} \tag{7}$$

where $Z_S' = \big(z_S(1+x_S), \tilde{z}_S(1+\tilde{x}_S), \tilde{z}_R(1+\tilde{x}_R)\big)$. The laws of motion for β and μ are given exogenously and depend only on t; below we specific the exact laws of motion. In short, a Rest-of-the-Country producer innovates in order to maximize period profits, minus innovation costs, plus the discounted value of future profits.

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

$$V_R(Z_R;\beta,\mu,t) = \max_{x_R}\Big\{(1-\beta)\Pi_R(Z_R,X_R;\beta,\mu) - I(x_R,Z_R) + \delta V_R\big(Z_R';\beta',\mu',t+1\big)\Big\} \tag{8}$$

where $Z_R' = \big(z_R(1+x_R),\tilde{z}_R(1+\tilde{x}_R),\tilde{z}_S(1+\tilde{x}_S)\big)$. Thus, the Rust Belt producer picks its technology upgrade to maximize its share of period profits, minus the cost of innovation, plus the discounted value of future profits. Rather than keeping all the current period profits, the firm only gets the share $(1-\beta)\Pi_R(Z_R,X_R;\beta,\mu)$. Note that in this environment, union bargaining acts like a tax on profits.

Finally, letting $i \in \{R,S\}$ denote the region, we assume that the investment cost function is

$$I(x_i,Z_i) = x_j^{\gamma}\frac{\overline{c}\, z_i^{\sigma-1}}{\lambda\tilde{z}_R^{\sigma-1}+(1-\lambda)\tilde{z}_S^{\sigma-1}} \tag{9}$$

for $Z_i = (z_i,\tilde{z}_i,\tilde{z}_{-i})$, $\gamma > 1$, and $\overline{c} > 0$. This cost function is increasing and convex in x_i. Note that the cost of innovation is decreasing in the size of the gap between the incumbent's productivity level and the geometric average of the productivity level in the economy. An important feature of this cost function is that it delivers balanced growth when the Rust Belt and the Rest of the Country have the same levels of product and labor market competition, i.e. $\beta = \mu = 0$ in all current and future periods. We call this *the competitive state*, and restrict the path for β and μ such that the economy reaches the competitive state in a finite number of periods T.

5.6. Dynamics in the Competitive State

In the competitive state, output and labor market conditions are characterized by $\beta = \mu = 0$ for all periods. One can show that two properties hold in the competitive state. First, the ratio z_R/z_S is constant over time. Second, employment shares across the two regions are constant over time. These properties imply that, in the competitive state, the aggregate economy is on a balanced growth path and both regions grow at the aggregate rate. Thus, changes in employment shares can only come about from differences in competitive pressure between the two regions, and not from differences in the productivity levels of the two regions, per se. In addition, these properties are useful in the model calibration since they enable us to characterize the competitive state largely by hand. This makes the long run properties of the model transparent and tractable.

5.7. Dynamics under Imperfect Competition in the Rust Belt

We now consider the economy when $\beta > 0$ or $\mu > 0$. As we show below, when plausibly calibrated, the model predicts that in this state there is less innovation (and hence productivity growth) in the Rust Belt than elsewhere. This in turn leads the relative price of the Rust Belt's goods to rise and, because goods are gross substitutes, demand for Rest of the Country's goods to rise. Thus, as in the model of Ngai and Pissarides (2007), employment flows out of the Rust Belt.

The distortion in labor markets, β, reduces innovation, as bargaining acts as a tax on the return to innovation. Firms bear the full cost of innovation but receive only the fraction β of the return, while members of the labor union appropriate the remaining share $1-\beta$. As a result, firms invest less *ex ante* than they otherwise would. By itself, this force leads to a decline in the Rust Belt's share of employment.

The output market distortion μ has two distinct effects on the innovation decisions of Rust Belt producers. First, higher market power in the current period leads to the *escape-the-competition* effect (Aghion, Akcigit, and Howitt, 2014), which reduces innovation. All else equal, the less competitive the fringe is today (i.e. the higher is μ in the current period), the weaker is the incumbent firms' incentive to invest today and thus distance themselves from the fringe. Second, higher market power in the future (i.e. higher μ in future periods) leads to the *Schumpeterian* effect, which increases innovation in the present. The higher market power is in future periods, the more firms get to enjoy the returns to innovations made today.

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 product and labor markets. We calibrate the differences in output and labor market competition between the Rust Belt and the Rest of the Country using evidence on wage premia and markups. We find that our baseline calibration of the model accounts for around two-thirds of the observed drop in 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. In terms of initial conditions, we set the productivities of the two regions in 1950 to $z_S = z_R = 1$, though our results are not sensitive to these initial values.

We calibrate the remaining four parameters jointly: ϕ, which governs the catch-up rate of the fringe; λ, which pins down the share of goods produced in the Rust Belt; γ, which is the curvature parameter in the cost function associated with innovation; and $\overline{c}$, which is the (linear) scale parameter in that same function.

We impose four empirical restrictions on the model to discipline these parameter values: *(i)* an average markup of 18 percent in the Rest of the Country, which is consistent with what Collard-Wexler and De Loecker (2015) estimate for the period since 1980 among minimill steel producers (most of which were located outside the Rust Belt); *(ii)* the initial employment share of 51 percent in the Rust Belt, corresponding to the actual share in 1950; *(iii)* 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); and *(iv)* a long-run output growth rate in the symmetric competitive state of 2 percent per year.

While in general there is a complex mapping between these empirical restrictions and the parameters, it turns out that ϕ largely determines the markup in the Rest of the Country, that λ largely determines the Rust Belt initial employment share, that γ largely determines the investment-to-output ratio, and that $\bar{c}$, given γ, exclusively determines the long-run growth rate of output.

We pick the paths $\{\beta_t\}_{t=1}^{T}$ and $\{\mu_t\}_{t=1}^{T}$ to match data on wage premia and markups from the Rust Belt. The wage premia come from our estimates of Figure 2, and the markups come from estimates from the integrated steel producers (almost all of which were located in the Rust Belt) of Collard-Wexler and De Loecker (2015). These data suggest that bargaining power and monopoly power remained roughly constant between 1950 and the early 1980s. By 1985, however, the data suggest that the strength of these distortions began to steadily decline. We capture this by solving the economy with constant parameter values for μ and β in 1950 through 1985, followed by a linear decline toward the absorbing competitive state by some future date T.[14]

We choose constant values for β and μ to match average wage premia and markups from 1950 to 1985 (corresponding to the first eight periods in the model). We match the observed decline post-1985 so as to match the wage premium and markup in the year 2000. The targeted wage premia and markups are listed in the table below.

Targeted Rust Belt Wage Premia and Markups

	Wage Premium	Markup
Average for 1950-1985	0.12	0.32
2000	0.02	0.24

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[14] More formally, $\mu_{t+1} = \mu_t$ and $\beta_{t+1} = \beta_t$ for $t \in \{1,\dots,8\}$, $\mu_{t+1} = \max\{0, \mu_t - \Delta_\mu\}$ and $\beta_{t+1} = \max\{0, \beta_t - \Delta_\beta\}$ for $t \in \{9,\dots,T\}$ and $\mu_t = \beta_t = 0$ for $t > T$, where parameters Δ_μ and Δ_β govern the speed of the decline in μ and β.

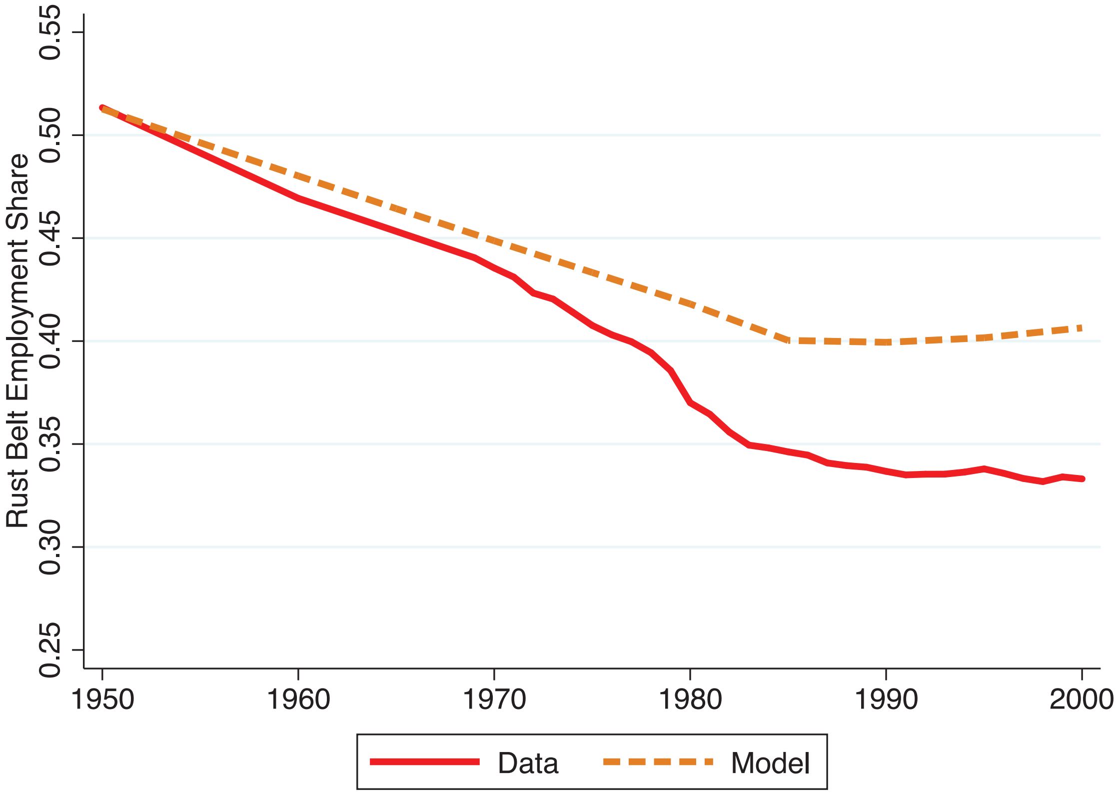

Figure 4: Manufacturing Employment Share in Rust Belt: Model and Data

In our quantitative analysis we characterize the equilibrium path of the model by solving the sequence of dynamic programs given by equations (7) and (8), given $\{\beta_t\}_{t=1}^{T}$ and $\{\mu_t\}_{t=1}^{T}$, using piecewise linear approximations to the value functions.[15]

6.2. Quantitative Results

Figure 4 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 11.4 percentage points, compared to 17 percentage points in the data. Thus, the model accounts for around two-thirds of the overall decline in the data.

The second salient feature of Figure 4 is that the model's predicted decline is more pronounced between 1950 and 1985 than in later years, and that, again, mirrors the decline in the data. The

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[15] Appendix A details the solution procedure. The parameter values implied by these restrictions are $\phi = 0.963$, $\lambda = 0.599$, $\gamma = 1.566$ and $\overline{c} = 3.01$. We can characterize the paths $\{\beta_t\}_{t=1}^{T}$ and $\{\mu_t\}_{t=1}^{T}$ by their first element and the absolute decline, Δ_β and Δ_μ, respectively, that kicks in at time $t = 9$. They are $\beta_1 = 0.225$ and $\Delta_\beta = 0.059$ for the union's bargaining power, and $\mu_1 = 0.136$ and $\Delta_\mu = 0.019$ for the Rust Belt producer's market power.

model predicts a drop of 12.5 percentage points until 1985, compared to a 15.2 percentage point drop in the data. After 1985, the Rust Belt's employment share declined just 2.8 percentage points in the data while the model predicts a small 1.1 percentage point increase in the Rust Belt's share.

Why does the model predict a steeper decline before 1985 than afterwards? The reason is that low competitive pressure before 1985 depresses innovation in the Rust Belt, and thus lowers productivity growth. This persistent cross-regional difference in productivity growth leads to a persistent 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. By 1985, the rise in competitive pressure (lower values of β_t and μ_t) generates lower Rust Belt markups, more moderate wage premia, and higher productivity growth. This in turn arrests the decline in the Rust Belt's share of employment.

While we do not target labor productivity growth rates in our calibration, the model performs well from 1950-1985 in this respect. It generates an average growth rate of 1.9 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 2.7 percent (model) and 2.6 percent (data). Thus, the model delivers rates and regional rate differentials that track their empirical counterparts closely in this period. After 1985, 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 from around 1.75 percent in 1980 to around 1.94 percent in 2000. The model is more successful in predicting the closing of the gap in productivity growth between the Rust Belt and Rest of the Country. In the model, the gap closes from around 0.8 percent per year in 1980 to around 0.2 percent per year in 2000, which is close to the data.

One place the model is less successful is in capturing the acceleration in the Rust Belt's decline from the late 1970s to early 1980s. One way of reconciling the model and data here is to let competition in output markets increase before competition in labor markets, as some evidence suggests happened. If we allowed μ to fall one period prior to the labor market transition, the decline would temporarily sharpen in the early 1980s and the post-1985 stabilization would be more muted. A second place the model's predictions could be improved is in the most recent part of the time period, where the model predicts a slight rise in the Rust Belt's employment share, while the data does not. The model's predicted increase is due largely to the steady decrease in Rust Belt markups over this period, which lower the region's relative prices. In reality, there likely were other countervailing factors leading to a continued decline.

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 1985 when competitive pressure was at its lowest. In the model, the investment-to-value added ratio averages 7.7 percent in the Rust Belt, compared to 9.2 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 8.

6.3. 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 the range of σ running from 2.4 to 3, which is centered around the most conservative estimates in Broda and Weinstein (2006). For brevity, we describe our results here but present them in more detail in Appendix Table 8. We find that when the elasticity is set to 2.4, the Rust Belt's employment share drops by 10.6 percentage points, compared to 11.4 in the benchmark calibration. With a higher elasticity of 3, the Rust Belt loses 12.2 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 62 percent to 72 percent of the Rust Belt's decline, similar to our benchmark exercise.

The second sensitivity analysis is over the parameter 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 2 percent steady-state growth target – which requires a change in $\bar{c}$ – and fix ϕ, μ, β, λ, and σ at their baseline values. The Rust Belt's employment share falls 9.1 percentage points when investment share is 8 percent, compared to the 11.4 percentage points in the benchmark. When we instead target a 9 percent investment-to-output ratio, the Rust Belt looses 14.6 percentage points. The higher investment rate leads to a sharper decline of the Rust Belt since holding up innovation now leads to lower relative productivity growth. For either of these alternative targets, the model accounts for half or more of the actual decline.

6.4. Interaction Effects of Output Market and Labor Market Competition

Our mechanism emphasizes the joint impact of non-competitive rents in output markets and the union's ability to hold up the firm as two different aspects of the Rust Belt's decline. In order to illustrate the effect of each one individually, we conduct three counterfactual experiments. What we find is that both effects are central in accounting for the data.

Table 2 reports the results. In the first row, we reproduce the employment decline, markups,

Table 2: Counterfactual Experiments

Experiment	Decline (percentage points)	Markup		Wage Premium	
		1950-85	2000	1950-85	2000
Benchmark	11.4	32%	26%	12.0%	2.0%
Low bargaining power (β)	4.2	35%	24%	6.5%	1.0%
Low monopoly power (μ)	11.2	21%	19%	7.9%	1.5%
Low monopoly power + match wage premium	19.7	18%	19%	12%	2%

and wage premia from the benchmark parameterization. In the second row, we cut the union's bargaining power in half and leave all the other parameters unchanged. Since Rust Belt producers are now relatively unencumbered by the labor unions, there is less hold up, and the employment share decline is just 4.2 percentage points. The union's wage premium is counterfactually low, however, at just 6.5 percent. In the third row, we restore the union's bargaining power but reduce the Rust Belt producer's market power instead. The employment decline is similar to our benchmark calibration, but both the markups and wage premia are counterfactually low. With fewer rents on the table, Rust Belt producers are more sensitive to the union's ability to hold up sunk investments. They innovate a lot less for precisely this reason. The corresponding lack of productivity growth further diminishes the producers' rents and labor unions fail to obtain much in the form of wage premia.

Finally, in the last row we check if we can generate the observed union wage premia when rents are more scarce. Like in the previous experiment we cut the producers' monopoly power in half and give the union enough bargaining power to generate the same wage premia as in the benchmark (12 percent for 1950-85 and 2 percent for 2000). Particularly in the earlier period, the union's strong bargaining position dampens the Rust Belt producers' appetitive for innovation and the employment decline exceeds the observed drop in the data.

The experiments in Table 2 illustrate key interaction effects between competitive pressure in product and labor markets. A significant lack of competition in both of these markets is required to generate empirically plausible Rust Belt markups and wage premia.

6.5. Stochastic Version

In both the model and the quantitative exercises so far the economy is populated by agents with perfect foresight. To assess how restrictive this assumption is, we solve a stochastic version of the model. In particular, rather than paths specifying the extent of labor and output market competition, the state of the economy follows a Markov process. In this version of the model, $\theta = (\beta, \mu)$ takes on one of three values. Formally, $\theta_t \in \{\theta_H, \theta_L, \theta_C\}$, where θ_H represents a high-distortion state, θ_L represents a low-distortion state, and θ_C has the same competition in product and labor markets as the Rest of the Country.

The transition from one state to another is governed by the following transition matrix.

	θ_H	θ_L	θ_C
θ_H	$1-\varepsilon$	ε	0
θ_L	0	$1-\varepsilon$	ε
θ_C	0	0	1

We place some restrictions on this matrix to keep it parsimonious and to ensure that competitive pressure increases over time in the Rust Belt. From either the high-distortion or low-distortion states, with probability ε the economy transitions to the symmetric competitive state, which is absorbing. With probability $1-\varepsilon$ the economy stays in the same state. All other model components remain the same.

The corresponding Bellman equation for a Rest of the Country producer is:

$$V_S(Z_S;\theta) = \max_{x_S} \left\{ \Pi_S(Z_S, X_S;\theta) - I(x_S, Z_S) + \delta \mathbb{E}\Big[V_S\big(Z_S;\theta'\big) \Big] \right\}, \tag{10}$$

where the expectation is over θ', tomorrow's state of competition.

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

$$V_R(Z_R;\theta) = \max_{x_R} \left\{ (1-\beta)\Pi_R(Z_R, X_R;\theta) - I(x_R, Z_R) + \delta \mathbb{E}\Big[V_R\big(Z_R';\theta'\big) \Big] \right\}. \tag{11}$$

We solve for the Bellman equations as functions of the exogenous states and then simulate an economy that starts off in state θ_H in 1950. The economy remains in this state until 1985, when it shifts to state θ_L, and remains there. The values for the parameters β and μ are chosen to target markups and wage premia, as before. The remainder of the calibration strategy is unaffected by the switch to an imperfect foresight environment.

The evolution of the Rust Belt's employment share in this version of the model is quite similar to the deterministic case, with the exception that there is a small, discrete increase in the Rust Belt's employment share in 1985, which stems from the discrete reallocation of employment into the Rust Best associated with the shift in market power and hence limit prices. Overall, the Rust Belt declines by 10.3 percentage points in this version, compared to 11.2 percentage points in the benchmark model.

7. Extension with Forward-Looking Union

This section modifies the model by replacing the static labor-bargaining model with a forward-looking union that maximizes the present discounted value of its wage premia. As before, we assume that the union is unable to commit to future actions, and that the union and firm bargain after the firm's investment is made. However, now we assume that the union takes into account how its actions today impact its future returns. We parameterize this version of the model to match the same targets as before, and then compare the model's predictions to those of the previous (stochastic) version of our model. We find that the Rust Belt's employment-share decline in this version is identical to that of the model with the static union.

7.1. Environment

Each period, the union proposes to receive a fraction $b_t \in (0,1)$ of the period profits in the form of a wage premium, and the firm either accepts or rejects the proposal. If the firm accepts the proposal, the union and firm split the profits with shares b_t and $1-b_t$. If the firm rejects the proposal, the union holds a strike. With (exogenous) probability β_t the strike succeeds, and no output is produced in period t. With probability $1-\beta_t$ the strike fails, in which case workers earn only the competitive wage.

Letting R_t be the rents (wage premia) that the union receives at date t, the union prefers higher values of

$$\sum_{t=0}^{\infty} \delta^t R_t, \tag{12}$$

where R_t depends on b_t and other variables of the model. To illustrate how b_t affects R_t, consider an offer $b_t > \beta_t$. By accepting the offer, the firm earns a fraction *less* than $1-\beta_t$ of the period profits. By rejecting the offer, the firm (in expectation) earns a fraction $1-\beta_t$ of the surplus, since with probability $1-\beta_t$ the firm earns the whole surplus, and with probability β_t the firm earns nothing. Thus, the firm will always reject any offer $b_t > \beta_t$. By a similar line of reasoning, the firm will always accept an offer $b_t \leq \beta_t$.

The union may choose to propose b_t strictly less than β_t if doing so induces sufficiently high investment by the firm that the higher future wage premia more than offsets the lower current premium. Thus, the union may choose a sequence of b_t's such that $b_t < \beta_t$ for some periods t. If so, then the decline of the Rust Belt generated by this version of the model would be lower than if the union chose $b_t = \beta_t$ in every t.

To assess the predictions of this model, we assign parameter values to match the same targets as in the benchmark model, including the same targets for markups and wage premia. The union chooses a state-contingent policy for its choice b. Formally, for a given endogenous state $Z_R \equiv (z_R, \tilde{z}_R, \tilde{z_S})$, exogenous state θ, and given policy functions $x_R(Z_R, \theta)$ and $x_S(Z_S, \theta)$, we solve for a policy function $b(Z_R, \theta)$. The Bellman Equation for the union's problem can be written as

$$V_U(Z_R; \theta) = \max_{b \leq \beta} \left\{ b\tilde{\pi}_R(Z_R, X_R, \theta) + \delta \mathbb{E}\left[V_U\left(Z_R'; \theta'\right) \right] \right\} \tag{13}$$

where the expectation $\mathbb{E}[\cdot]$ is over realizations of θ', and where the investment policy function $x_R(z_R, Z, \theta)$ by the Rust Belt takes as given the union's policy function.

An equilibrium of this model consists of value functions and policy functions for (1) the union, (2) the Rust Belt firms, and (3) the Rest-of-the-Country firms, such that (1), (2) and (3) solve their problem taking the others' policy rules as given, markets clear, and expectations are correct.

7.2. Quantitative Results

We begin by considering the same parameter values as in the benchmark model, and the same policy experiment as the stochastic version of the model, which begins the economy in the high-distortions state, θ_H, and moves to the low distortion state, θ_L, in 1985. One can think of the drop in β_t in 1985 as representing an exogenous decline in the probability that a strike will be successful; this is consistent with Figure 3, which shows that strikes fell substantially at that time.

Our main finding is that the Rust Belt's employment-share decline is identical to that of the benchmark model. The reason is that the the union always chooses $b_t = \beta_t$ in this version, and the value for β is the same as in the previous model. Thus, the hold-up is equally strong in this model as in the benchmark model, and the quantitative predictions are the same.

To get some insight into when the forward-looking union may choose $b_t < \beta_t$, we conduct two alternative quantitative experiments. In both experiments we set $\beta_t = 1$ for all t, so that the union is unconstrained by its choice of the share of current profits it should receive. In the first experiment, we reduce ε, the expected probability of moving to the low-distortion state, to 0.01. This simulates an environment where all parties expect the high distortions in output markets to be in place for a long time. One may expect that this will give unions a stronger incentive not to take too much of current profits, since by doing so they reduce future profits (and hence their future wage premia). We find that lower ε is not enough for the union to exercise restraint: in this case the union proposes $b_t = 1$ each period. The reason is that the high markups imply high profits each period even when the union takes all of the profits and the firm does not invest at all.

In the second alternative experiment, we increase ϕ, the catch-up parameter of the fringe, to $\phi = 1$, and we reduce the monopoly distortion to $\mu = 0$. With these changes, the Rust Belt firms face strong competition from the fringe each period, and must invest in order to earn any profits. In other words, the escape-competition effect is particularly strong. Knowing this, the union takes into consideration that the current-period profits are highly dependent on the firm's investment, and hence highly dependent on the union's chosen share of the surplus. One may expect that the unions choose a lower share in this case. Indeed, we find that the union proposes a 40-60 split, on average over the time period. Since the producers accept any $b \in [0,1]$ in equilibrium, this means that unions appropriate roughly 40 percent of the period profits and the firms keep the remainder.[16] The reason is that, when competition in output markets is high, unions reduce the extent to which they hold up the firm, since by holding up the firm they substantially reduce their own rents.

In conclusion, this extended model shows that when unions are given the option to exercise restraint, they do so only when output-market competition is strong enough. In contrast, when output market competition is low, as in the benchmark parameterization of the model, unions find it in their best interest to hold up the firm even if that chokes off investment. Thus, this extended model paints a more nuanced picture of the interactions between competition in output markets and labor markets. Our quantitive experiments here suggest that competition in output markets is a strong complementary force to competition in labor markets.

8. Supporting Evidence

In this section we present additional evidence supporting the model's predictions. We first discuss some direct evidence that expenditures on research and development (R&D) were relatively low in some important Rust Belt industries. Second, we show that technology adoption lagged in these same 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

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[16] Moreover, the union's proposal is (weakly) increasing in ε. When the economy is more likely to be in a more competitive state (with fewer rents) tomorrow, the unions have stronger incentives to appropriate a large share of today's returns. In the extreme, when the economy transitions to the competitive state with certainty, then unions choose $b_t = \beta_t$.

low innovation played an important role in the decline of the Rust Belt.

8.1. R&D Expenditures

The first piece of evidence we consider is on R&D expenditures by industry. Expenditures on R&D provides a nice example of costly investments that are taken to improve productivity, as in the model. Evidence from the 1970s suggests that R&D expenditures were lower in key Rust Belt industries, in particular steel, automobile and rubber manufacturing, than in other manufacturing industries. According to a study by the U.S. Office of Technology Assessment (1980), the average manufacturing industry had R&D expenditures totaling 2.5 percent of total sales in the 1970s. The highest rates were in communications equipment, aircraft and parts, and office and computing equipment, with R&D representing 15.2 percent, 12.4 percent and 11.6 percent of total sales, respectively. Auto manufacturing, rubber and plastics manufacturing, and “ferrous metals,” which includes steelmaking, had R&D expenditures of just 2.1 percent, 1.2 percent and 0.4 percent of total sales.

8.2. 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).[17]

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 ...

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[17] 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.

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

8.3. 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.[18]

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

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[18] 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.

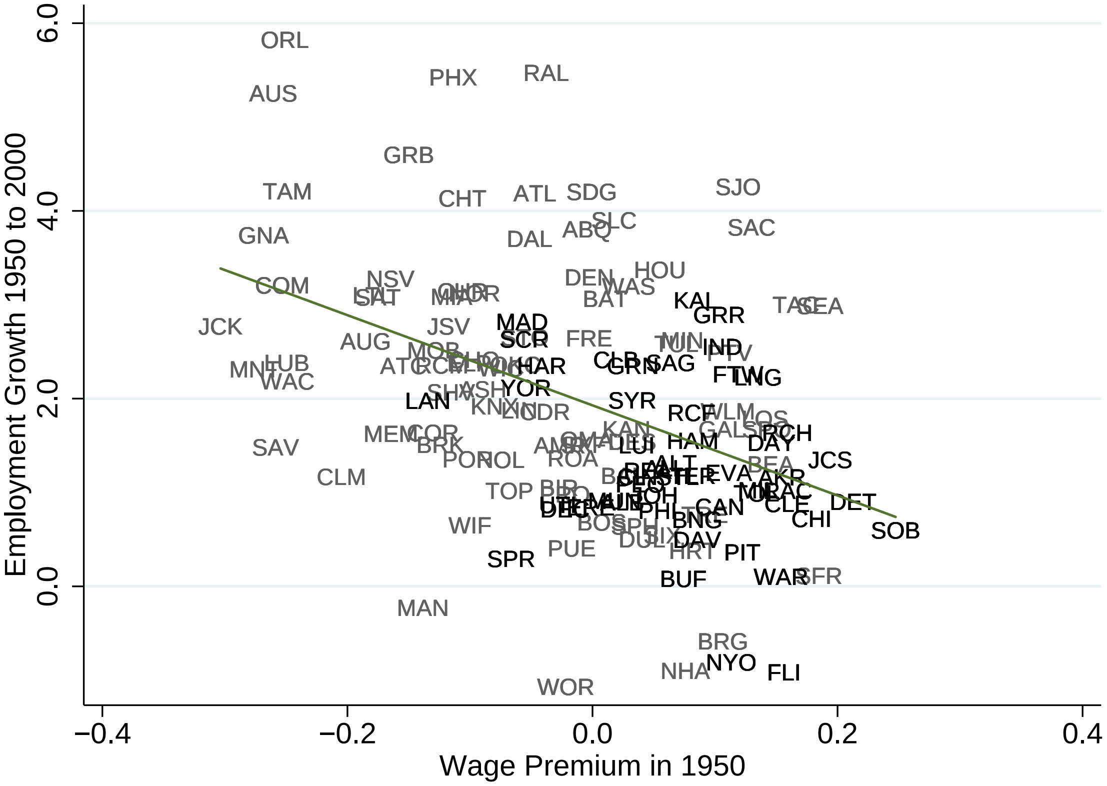

Figure 5: Wage Premiums and Employment Growth across MSAs

particular, we assume that the log hourly wage of worker i in region m is

$$\log w_{i,m} = \alpha \cdot SCHOOL_{i,m} + \sum_{j=1}^{4} \beta_j \cdot EXPER_{i,m}^{j} + \sum_{m=1}^{M} D_m \cdot \pi_m + \varepsilon_{i,m} \tag{14}$$

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

Figure 5 shows the wage premium in 1950 (normalized to 0) plotted against the annualized growth in employment from 1950 to 2000. Rust Belt MSAs are displayed in 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.[19]

9. Conclusion

This study documents 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. We find that lack of competition was an important contributing factor to the decline of the Rust Belt, and that the increase in competitive pressure around the 1980s accounts for the large change in the pattern of the decay in the Rust Belt employment share at that time. In our model, the decline of the Rust Belt reflects interactions between output-market competition and labor-market competition that led Rust Belt producers to innovate at a relatively low rate, and in turn fostered a shift of economic activity to the rest of the country.

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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[19] One potential alternative theory of the wage premiums in the Rust Belt is that workers there tended to be of higher-than-average ability. One piece of evidence against this hypothesis is that workers in industries common in the Rust Belt tended to suffer some of the largest wage losses in percent terms after a (plausibly) exogenous displacement, compared to workers in other industries (Carrington and Zaman, 1994; Jacobson, Lalonde, and Sullivan, 1993). Carrington and Zaman (1994) find that displaced workers in the typical industry lost about 10 percent of their pre-displacement wage when moving to a new job. In contrast, workers in the "primary metal manufacturing" industry lost around 26 percent of their wages, and workers in "transport equipment manufacturing" and "rubber and plastics manufacturing" lost around 20 percent.

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Appendix (for Online Publication)

A. Computational Procedure

We solve the dynamic program using a piecewise linear value function with interpolation and multi-grid value function iteration. Since an individual producer takes the policies of all other producers as given, we nest the various value function iterations appropriately.

We initiate the computational procedure by solving the producers' problem in the (absorbing) competitive state. Since the economy is symmetric with respect to Rust Belt and Rest-of-Country producers, we can characterize the equilibrium technology investment x along the balanced growth path as the solution to a single non-linear equation. In the perfect foresight version of the model, the economy transitions to this stationary state in a finite number of periods and we denote the corresponding calendar year by T. For this reason, the entire dynamic program is stationary.

Characterizing the dynamic equilibrium along the unbalanced growth path is computationally more challenging. To illustrate the procedure, we describe the solution algorithm for a single iteration in the sequence of Bellman equations indexed by $t \in \{1950, 1955, \ldots, T\}$. In particular, let us consider the procedure when the economy is in (β_{T-5}, μ_{T-5}) (that is, the last period before the economy reaches the balanced growth path).

It is computationally convenient to exploit a scale invariance property of the model. What matters is the productivity of an individual producer i relative to all other producers in the economy, and not the absolute level $z(i)$. We express all productivities – idiosyncratic and aggregate – relative to the Rest of the Country producers and organize the state space on grid with N points. Moreover, let i index the idiosyncratic productivity of a single producer; j labels the productivities of all other producers in the economy.

With this in mind, let us consider the problem of an individual Rust Belt producer with productivity $z_R(i)$ when all other Rust Belt producers use the technology $\tilde{z}_R(j)$ and the productivity of all ROC producers is $\tilde{z}_S(j)$. In general, a variable with a tilde denotes states and policies of a producer's peers.

To begin with, the producers using the technologies $\tilde{z}_R(j)$ and $\tilde{z}_S(j)$ make technology investments according to their respective policy functions in the state (β_T, μ_T). Let this initial policy of all the Rust Belt producers be $\tilde{x}_R^0\left(\frac{\tilde{z}_R(j)}{\tilde{z}_S(j)}, 1; \beta_{T-5}, \mu_{T-5}\right)$. Given next period's value function, denoted by $V_R(\cdot;\beta_T,\mu_T)$, an individual Rust Belt producer makes a profit-maximizing technology investment $x\left(\frac{z_R(j)}{\tilde{z}_S(j)},\frac{\tilde{z}_R(j)}{\tilde{z}_S(j)},1;\beta_{T-5},\mu_{T-5}\right)$ that depends on the idiosyncratic and aggregate states of the economy. We compute this investment for each pair $(i,j)\in\{1,\ldots,N\}\times\{1,\ldots,N\}$.

Next, we update the policy functions of i's peer producers in the Rust Belt. For each (i,j), their technology investment is given by:

$$\tilde{x}_R^1\left(\frac{\tilde{z}_R(i)}{\tilde{z}_S(j)},1;\beta_{T-5},\mu_{T-5}\right)=\lambda x\left(\frac{z_R(j)}{\tilde{z}_S(j)},\frac{\tilde{z}_R(j)}{\tilde{z}_S(j)},1;\beta_{T-5},\mu_{T-5}\right)+(1-\lambda)\tilde{x}_R^0\left(\frac{\tilde{z}_R(j)}{\tilde{z}_S(j)},1;\beta_{T-5},\mu_{T-5}\right)$$

Note that the update assumes individual producers have not, in the past, deviated from the symmetric equilibrium. That is, for all (i,j), the "innovation" is given by $x\left(\frac{z_R(j)}{\tilde{z}_S(j)},\cdot,\cdot;\beta_{T-5},\mu_{T-5}\right)$ rather then $x\left(\frac{z_R(i)}{\tilde{z}_S(j)},\cdot,\cdot;\beta_{T-5},\mu_{T-5}\right)$.

We then iterate to convergence over $\tilde{x}_R^{n-1}$ and $\tilde{x}_R^n$, for $n\in\{1,2,\ldots\}$. Since $V_R(\cdot;\beta_T,\mu_T)$ is piecewise linear, we have to anticipate the possibility that the iteration over the policy functions may not converge in the neighborhood of a kink (i.e. a grid point). Whenever such a trap emerges, we add a grid point to the state space in a way that smoothes the value function locally and we update the dimensions of all other policy and value functions analogously.[20] Once the policy functions have converged we compute the value function $V_R^0(\cdot;\beta_{T-5},\mu_{T-5})$.

Next, we solve the problem of a producer in the Rest of the Country. Importantly, the initial policy function of all other producers $\tilde{x}_S^0\left(\frac{\tilde{z}_R(i)}{\tilde{z}_S(j)},1;\beta_{T-5},\mu_{T-5}\right)$ takes into account the Rust Belt producers' investment choices from the previous step. An individual Rest of the Country producer's investment decision is denoted by $x\left(\frac{z_S(i)}{\tilde{z}_S(j)},\frac{\tilde{z}_R(j)}{\tilde{z}_S(j)},1;\beta_{T-5},\mu_{T-5}\right)$ and the iteration to convergence over policy functions is analogous to the procedure for Rust Belt producers. Once the sequence of policies has converged, we compute $V_S^0(\cdot;\beta_{T-5},\mu_{T-5})$.

Lastly, we iterate over the Rust Belt and Rest of the Country's producers' problem to compute the sequences of value functions $\{V_R^m(\cdot;\beta_{T-5},\mu_{T-5}),V_S^m(\cdot;\beta_{T-5},\mu_{T-5})\}_{m=1,2,\ldots}$ until $V_R^m(\cdot;\beta_{T-5},\mu_{T-5})=V_R^{m-1}(\cdot;\beta_{T-5},\mu_{T-5})$ and $V_S^m(\cdot;\beta_{T-5},\mu_{T-5})=V_S^{m-1}(\cdot;\beta_{T-5},\mu_{T-5})$. Put differently, we stop when the investment decisions of the former are best responses to the latter and vice versa.

Once we have solved the dynamic program for (β_{T-5},μ_{T-5}) we proceed in exactly the same way for the entire sequence $\{\theta_{T-5t}\}_{t=2}^{\frac{T-1950}{5}}$.

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[20] We would like to thank Jesùs Fernandez-Villaverde for suggesting this multi-grid value function iteration.

B. Appendix Tables and Figures

Table 5: 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.

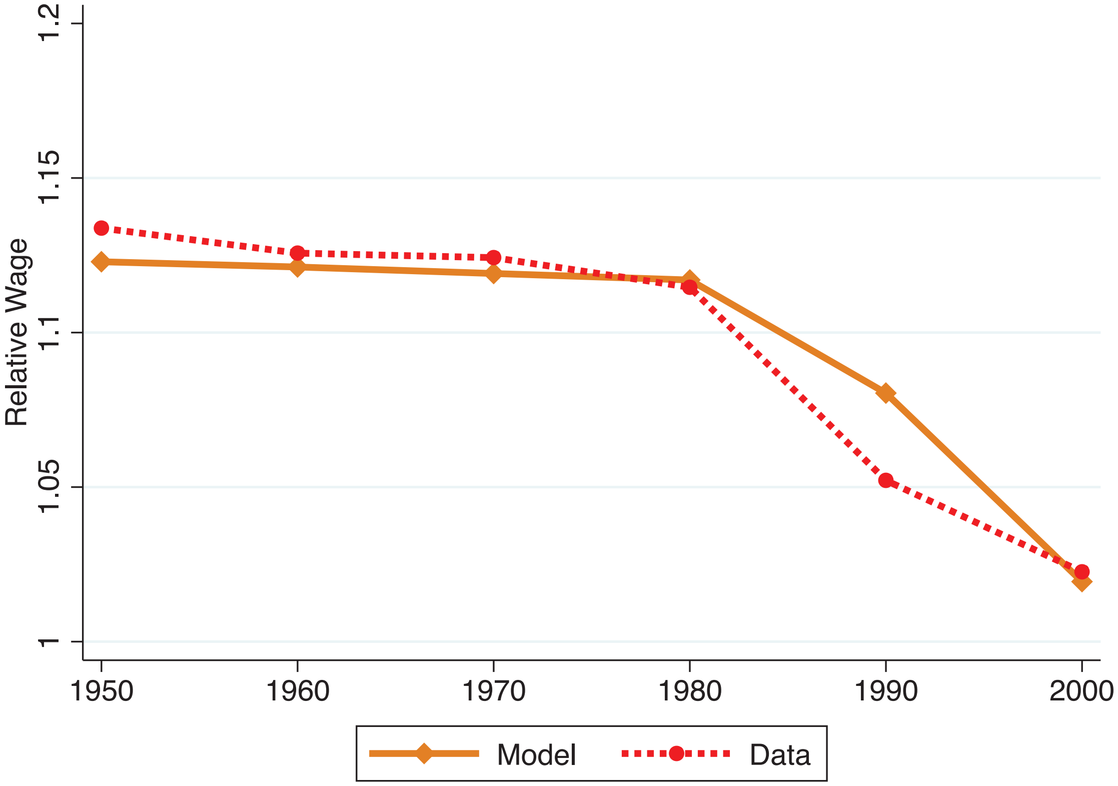

Figure 6: Wage Premium of the Rust Belt: Model and Data

Table 6: 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.

Table 7: Sensitivity Analysis to Investment-to-Output Ratio

Investment / GDP	8.0%	8.5%	9%
Rust Belt Employment-Share Decline	9.1	11.4	14.6
ROC Markup	17.5%	18.0%	18.5%
Rust Belt Markup 1950-1985	32.1%	32.0%	31.6%
Rust Belt Markup 2000	24.0%	24.0%	23.8%
Wage Premium 1950-1985	12.1%	12.0%	11.9%
Wage Premium 2000	2.0%	2.0%	1.9%

Note: Rust Belt Employment-Share Decline is the percentage point decline in the share of manufacturing employment in the Rust Belt. Wage Premium in the Rust Belt is the model's relative wage of Rust Belt workers to other workers between 1950 and 1980.

Table 8: Sensitivity Analysis to Elasticity of Substitution

Substitution Elasticity	Rust Belt Employment-Share Decline
$\sigma = 2.4$	10.6
$\sigma = 2.7$ (benchmark)	11.4
$\sigma = 3.0$	12.2

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