Labor Market Conflict and the Decline of the Rust Belt

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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 decline of the Rust Belt was due in large part to the persistent labor market conflict that was prevalent throughout the Rust Belt's main industries. We formalize this thesis in a two-region dynamic general equilibrium model in which labor market conflict leads to a hold-up problem in the Rust Belt that reduces investment and productivity growth and leads employment to move from the Rust Belt to the rest of the country. Quantitatively, the model accounts for much of the large secular decline in the Rust Belt's share of manufacturing employment. Consistent with our theory, data at the state-industry level show that labor conflict, proxied by rates of major work stoppages, is strongly negatively correlated with employment growth.

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1. Introduction

No region of the United States fared worse over the postwar period than the "Rust Belt," which is the heavy manufacturing region bordering the Great Lakes. In 1950, just over half of U.S. manufacturing employment was located in the Rust Belt. A half century later, in 2000, the Rust Belt employed just one third of U.S. manufacturing workers. The Rust Belt suffered similar declines in its share of manufacturing value added, aggregate value added and aggregate employment [1]

There is a general perception that increased manufactured imports are an important factor behind the decay of the Rust Belt. But imports – to whatever extent that they are associated with lower Rust Belt employment – are not an explanation. Rather, higher imports, as well as the Rust Belt's decline, are *endogenous outcomes* reflecting equilibrium responses to underlying market forces.

This paper proposes a theory of the Rust Belt's decline based on *persistent labor market conflict* between the region's manufacturing workers and firms. We develop a quantitative theoretic model that analyzes how labor conflict drove the evolution of U.S. regional employment shares and trade from 1950 to 2000. A large microeconomic literature has empirically studied Rust Belt labor markets at the industry and firm level, and concluded that conflicted labor relations significantly depressed Rust Belt competitiveness and productivity. This microeconomic literature, which we summarize below, cites the strike threat as an important channel depressing Rust Belt productivity. Our analysis thus represents a natural evolution of this microeconomic literature to a macroeconomic setting that analyzes how this conflict affected aggregate variables.

To study how labor market conflict affected the Rust Belt, we develop a dynamic general-equilibrium endogenous growth model with two domestic regions: the Rust Belt and the rest of the country. Both regions produce local services and manufactured goods that are traded with a foreign sector. The two domestic regions differ in that the manufacturing sector in the Rust Belt features labor conflict, whereas the service sectors of both regions and the manufacturing sector in the rest of the country feature competitive labor markets.

Labor conflict is modeled as a hold-up problem in which Rust Belt workers bargain with firms over industry rents after Rust Belt firms have made investments. This hold-up problem acts as a tax on investment and provides Rust Belt union members with higher wages than in the rest of the country. This de facto investment tax leads to lower investment by

[1] We define the Rust Belt as Illinois, Indiana, Michigan, New York, Ohio, Pennsylvania, West Virginia and Wisconsin. We discuss our data in detail in Section 2.

Rust Belt manufacturing firms relative to other firms that operate in competitive labor markets. Lower investment in the Rust Belt endogenously generates relatively low Rust Belt productivity growth and a shift in labor from the Rust Belt to the rest of the country. International competition is modeled using a simple Ricardian trade structure, in which the rest of the world has a growing comparative advantage in the manufactured goods similar to those produced in the Rust Belt (compared to those produced in the rest of the country). We discipline union bargaining power using the Rust Belt manufacturing wage premium. The impact of foreign productivity growth is disciplined using data on import shares in the United States as a whole and in the manufacturing industries that were concentrated in the Rust Belt.

Our main findings are as follows. The model, with both labor conflict and increased foreign competition operating, accounts for about 70 percent of the Rust Belt's decline. In a counterfactual experiment with neither force operating, we find that the Rust Belt would have expanded – rather than declined – over the postwar period. The reason is that the initial productivity advantage of Rust Belt manufacturing firms would have given them more incentive to invest, and faster growth over this period as a result. In a second counterfactual experiment that shuts down just the labor-conflict channel, our model predicts that the Rust Belt's share of U.S. manufacturing employment would have stayed largely the same in 2000 as in 1950.

We empirically evaluate the model predictions by analyzing the statistical relationship between labor conflict, measured as major work stoppages, and state-industry employment growth from 1950 to 2000. We include a number of controls, including industry fixed effects, state climate variables, to control for the shift of the population to warmer states (emphasized by Rappaport, 2007), initial state industry concentration and population, which Desmet and Rossi-Hansberg (2009) show matter for state manufacturing trends. We find that even with these controls, there is a statistically significant, negative relationship between strikes and state-industry employment growth. To address potential concerns of reverse causality, we evaluate an alternative measure of conflict that long predated post-war employment growth: strikes occurring between 1927 and 1934, compiled from data archived by the U.S. Bureau of Labor Statistics. These data show that strikes occurring between 1927 and 1934 are significantly negatively associated with employment growth from 1950 to 2000, which indicates a role for conflict in leading to poor employment outcomes, rather than the reverse.

Few prior papers have attempted to explain the root causes of the Rust Belt's decline. The one other of which we are aware is by Yoon (2017), who argues, in contrast to our work, that the Rust Belt's decline was due to rapid technological change in manufacturing. Some other papers are implicitly related to the Rust Belt decline. 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. Similarly, Desmet and Rossi-Hansberg (2009) argue that the declining importance of knowledge spillovers led formerly concentrated industries to spread out through space, and Duranton and Puga (2009) emphasize the declining costs of communication. None of these theories emphasize labor market conflict, however, as we do. A number of papers have studied the macroeconomic consequences of unionization, (see e.g. Borjas and Ramey, 1995; Bridgman, 2015; Taschereau-Dumouchel, 2015; Dinlersoz and Greenwood, 2016; Acikgoz and Kaymak, 2014), though none have related labor conflict to the decline of the Rust Belt.

The focus of our model on non-competitive labor markets builds on a growing literature that connects lack of competition with poor economic performance (see e.g. Acemoglu, Akcigit, Alp, Bloom, and Kerr, 2018; Pavcnik, 2002; Aghion, Bloom, Blundell, Griffith, and Howitt, 2005; Cole, Ohanian, Riascos, and Schmitz Jr., 2005; Schmitz, 2005; Holmes and Schmitz, 2010; Syverson, 2011; Peters, 2013), though our emphasis on hold-up has not received much prior attention in this literature. Our model's integration of depressed productivity growth with regional decline is related to models of structural change, in which differential employment dynamics and differential sectoral productivity growth go hand-in-hand (see e.g. Ngai and Pissarides, 2007; Buera and Kaboski, 2009; Herrendorf, Rogerson, and Valentinyi, 2014).

The rest of the paper is organized as follows. Section 2 summarizes the facts regarding the Rust Belt's employment-share decline, its high rates of labor conflict, its wage premium, and how these patterns changed staring in the 1980s. Section 3 presents the model economy. Section 4 quantifies the importance of labor conflict and international forces in the decline of the Rust Belt. Section 5 presents supporting evidence that labor conflict is a robust negative predictor of employment growth at the state-industry level. Section 6 concludes.

2. Decline of the Rust Belt: The Facts

This section documents a set of facts characterizing the Rust Belt's decline. We begin by showing that the Rust Belt's share of manufacturing employment declined secularly from 1950 to 2000, with much of the decline occurring before 1980. Second, we show that manufacturing industries in the Rust Belt had higher rates of work stoppages and unionization than manufacturing industries in the rest of the country or in service industries. Third, manufacturing industries in the Rust Belt paid substantial wage premiums. Fourth, we show that all these empirical patterns changed significantly after 1980, as labor conflict diminished, wage premia fell, and the region's decline slowed.

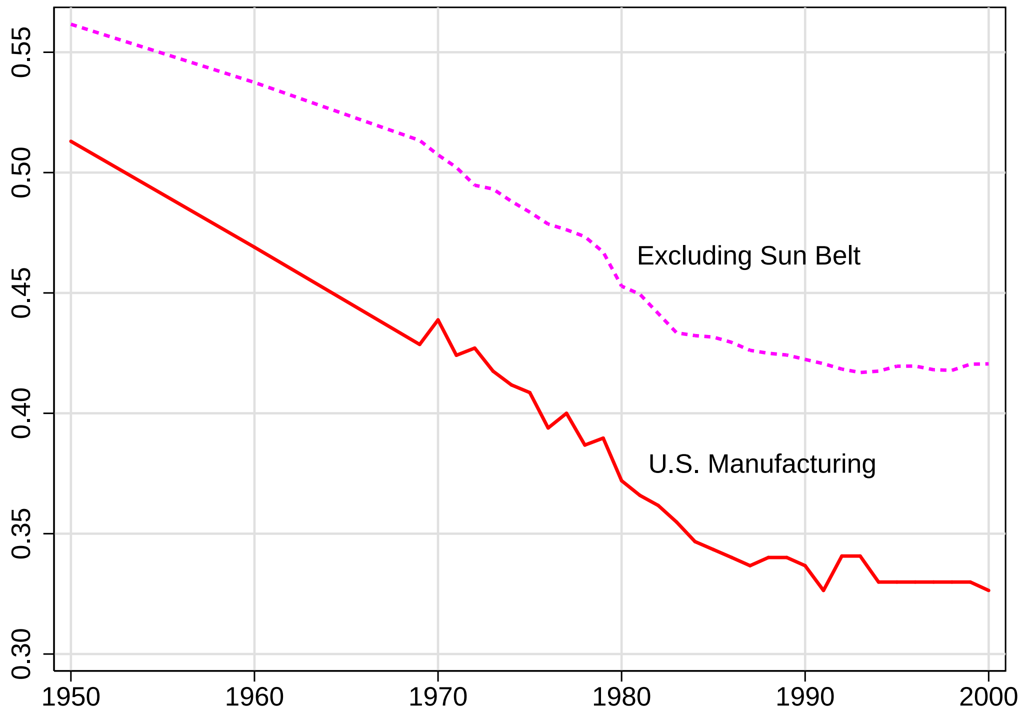
2.1. Decline of the Rust Belt's Employment Share

We begin with the basic fact that motivates this paper: the Rust Belt's share of employment decreased secularly over the postwar period. 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 sources are the U.S. Censuses of 1950 through 2000 and the Current Population Surveys, available through the Integrated Public Use Microdata Series (IPUMS). Throughout, we focus on private-sector wage workers. See Appendix A for a more detailed description of our data.

Figure 1 plots the Rust Belt's share of employment from 1950 through 2000 by two different metrics. The first is the share of U.S. manufacturing employment located in the Rust Belt (solid red), which began at 51 percent in 1950 and declined to 33 percent by 2000. Note that this decline represents a shift in employment within the U.S. manufacturing sector from the Rust Belt to the rest of the country, rather than the well-studied movement of employment from the manufacturing sector into services (see e.g. Buera and Kaboski, 2012). Furthermore, the decline of the Rust Belt's share of manufacturing employment is broad-based, affecting nearly all of the Rust Belt's 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 second metric we consider is the Rust Belt's share of U.S. manufacturing employment excluding the "Sun Belt" states of Arizona, California, Florida, New Mexico and Nevada (Blanchard and Katz, 1992). The share of manufacturing employment in states other than the Sun Belt states (dotted purple) was 56 percent in 1950 and 42 percent in 2000. This 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

Figure 1: The Rust Belt's Manufacturing Employment Share



Note: This figure plots the share of U.S. manufacturing employment located in Rust Belt states (red line) and the share of manufacturing employment in the United States – excluding the Sun Belt states of Arizona, California, Florida, New Mexico and Nevada – located in Rust Belt states (dashed purple line).

faster employment growth in the right-to-work state counties next to the border than in counties right across the state border.

More broadly, no region of the United States declined as much as the Rust Belt since the end of World War II. 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 manufacturing employment relative to the rest of the country.

2.2. Unionization and Major Work Stoppages

Next, we present patterns of unionization and labor conflict in the United States, and show that the highest rates of union membership and major work stoppages were in manufacturing industries located in the Rust Belt. We begin with unionization, using CPS data from 1973 to 1980, which are the earliest nationally representative unionization data (of which we are aware) that can be disaggregated by region and industry.

Table 1: Unionization and Major Work Stoppage Rates by Region and Industry

Panel A: Unionization Rates

	Manufacturing	Services	Overall
Rust Belt	48.1	22.5	30.9
Rest of Country	28.4	14.4	18.1

Panel B: Major Work Stoppages Rates

	Manufacturing	Services	Overall
Rust Belt	19.2	3.2	9.7
Rest of Country	2.7	0.9	1.6

Note: Panel A reports the unionization rate by region and broad industry. The data cover the years 1973 to 1980 and come from the CPS. Panel B reports the average percent of years in which there was a major work stoppage, defined as a work stoppage affecting 1,000 workers or more, by region and broad industry. The average is taken across all 3-digit manufacturing and service industries. The data cover the years 1958 to 1977 and come from the BLS.

Table 1, Panel A, reports the unionization rate by broad (private) industry and region for the years 1973 to 1980. The highest unionization rate was in Rust Belt manufacturing industries, where 48.1 percent of workers were union members. Manufacturing workers in the rest of the country were next at 28.4 percent, followed by service workers in the Rust Belt (22.5 percent) and service workers in the rest of the country (14.4 percent). To be sure, the finding that the most unionized industries in the United States were manufacturing industries in the Rust Belt is not new to our paper, and is in fact consistent with numerous previous studies of collective bargaining in the United States (see e.g. Goldfield, 1987; Kochan, Katz, and McKersie, 1994).

We next turn to data on work stoppages, which are arguably the best proxy for labor conflict available. In particularly, we draw on work stoppage data collected by the BLS in a consistent way from 1958 to 1977. The data include the industry, state and number of workers involved in each work stoppage. We define a major work stoppage to be one that affects 1,000 or more workers, which is a cutoff used by the BLS in their aggregate statistics. A work stoppage could be initiated by workers, in the form of a strike, or by management, in the form of a lockout. In either case, it is clear that a work stoppage is a symptom of conflict between workers and management.

Table 1, Panel B, computes the rates of major work stoppages by broad industry in the Rust Belt and the rest of the United States, measured as the percent of years involving a major work stoppage, on average, across three-digit industries. The highest rates of work stoppages were in the Rust Belt manufacturing industries, where, on average, 19.2 percent of years involved a major work stoppage. This rate of roughly one strike every five years is consistent with historical studies of labor relations in the Rust Belt's main manufacturing industries, such as Steel and Autos (see e.g. Richter, 2003). Rust Belt services had far lower rates of major work stoppages at 3.2 percent per year, as was manufacturing in the rest of the country at 2.7 percent per year and services in the rest of the country at 0.9 percent per year.

Work stoppage rates were proportionally far higher in Rust Belt manufacturing than in other regions or industries compared to unionization rates. Specifically, within manufacturing, unionization rates were about twice as high in the Rust Belt as the rest of the country, but rates of major work stoppages were about six times as high. This shows that labor relations in the Rust Belt were more prone to conflict than manufacturing industries outside of the Rust Belt (and services).[2]

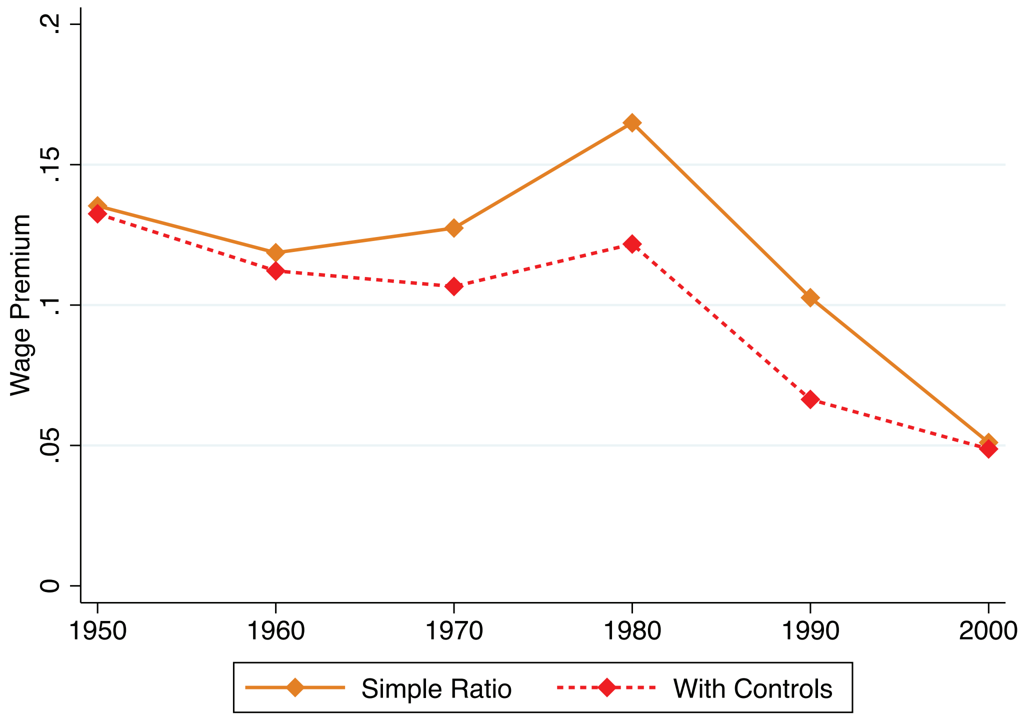
2.3. Wage Premia in Rust Belt Manufacturing

This section turns to data on relative wages of manufacturing workers in the Rust Belt. We focus on manufacturing workers because the evidence in the previous section points to conflict as being primarily within the Rust Belt's manufacturing sector. Figure 2 plots two different measures of the wage premium earned by manufacturing workers in the Rust Belt relative to manufacturing workers in the rest of the country. The first is the sample ratio of average manufacturing wages (minus one), plotted as a solid orange line. This simple wage premium started out at 13 percent in 1950, stayed between 12 and 16 percent through 1980, and then fall to 5 percent by 2000.

We address the possibility that the wage premium reflects better educated or more experienced workers by computing the residual wage premium after controlling for education,

[2]The fact that the Rust Belt manufacturing industries were the most conflicted in the United States is corroborated by numerous historical studies (see e.g. Lodge, 1986; Nelson, 1996). Moreover, it is widely agreed that the conflict began with the violent union organizations of these industries in the 1930s (Millis and Brown, 1950). For example, a 1982 National Academy of Sciences project on the U.S. auto industry argues that the violent union organizations and sit-down strikes of the late 1930s defined an "adversarial and bitter relationship between labor and management" (Clark, 1982). Barnard (2004), Katz (1985), Kochan, Katz, and McKersie (1994), Serrin (1973) and Strohmeyer (1986) also describe how the organization conflicts of the 1930s and 1940s evolved into chronically conflicted relations in which the strike threat dominated labor negotiations in many Rust Belt industries after World War II.

Figure 2: Wage Premium Earned by Rust Belt Manufacturing Workers



Note: This figure plots the ratio of average wages for manufacturing workers in the Rust Belt relative to manufacturing workers in the rest of the United States (orange line) and the dummy variable from a regression of log wages on a Rust Belt dummy variable and other controls, described in the text.

age, age squared and a sex dummy. This wage premium with controls is plotted as the dashed red line in Figure 2. It is very similar to the simple wage premium. The wage premium with these countrols is 13 percent in 1950, it remains between 11 and 13 percent through 1980, and falls about to 6 percent in 2000. Thus, even with these controls, manufacturing workers in the Rust Belt earned substantial wage premia until 1980.

Another possible factor affecting the wage premium is that the cost of living was higher in the Rust Belt than elsewhere. While time series on regional costs of living in the United States do not exist, the BLS did calculate city-level cost of living in a sample of 39 cities in one year, 1966, in the middle of our time period (U.S. Bureau of Labor Statistics, 1967).

These data show that the average cost of living difference in Rust Belt cities in 1966 are only about two percent or less, and are statistically insignificant (see Appendix A.1). Moreover, the premium earned by manufacturing workers in the Rust Belt was not shared by service workers located in the Rust Belt. For example, these non-manufacturing workers earned about 97 percent of the national average wage in 1950, and substantially less than Rust Belt manufacturing workers.

Given that standard human capital controls and that regional cost of living differences do not account for these premia, we pursue a union/labor-conflict explanation of these premia. There is considerably theory and evidence that the high unionization and work stoppage rates presented in the previous subsection are driving the wage premium earned by Rust Belt manufacturing workers. Farber (1986)'s survey chapter on union behavior shows that the standard view of unions is that of an organization that bargains over industry rents in the form of wage premia, and that rations scarce, high-paying union jobs in order to preserve those premia.

Models of union labor markets and job rationing are the focus of the large literature on insider-outsider models of unions developed by Lindbeck and Snower (1988), Blanchard and Summers (1986) and Cole and Ohanian (2004), in which unions restrict their membership to maximize rents per worker. These studies cite considerable evidence of union rents and union job rationing. More broadly, Dickens and Lang (1985, 1988) present evidence from CPS data that supports job rationing. Using CPS data from the early 1980s, they find a significant union wage premium after controlling for race, marital status, education, and experience. Moreover, they find evidence that jobs were rationed among white males.

Meier and Rudwick (1979) and Hinshaw (2002) provide detailed studies of the U.S. auto and steel industries, which were concentrated in the Rust Belt, and confirm Dickens and Lang (1985, 1988)'s finding that an important component of job rationing was sharply restricting union jobs offered to women and minorities. Another mechanism in rationing union jobs was nepotism in new hiring. Kupfberg (1999) describes discrimination lawsuits in which unions de facto discriminated against minority candidates by accepting new members who were referred by existing union workers, typically through family or friendship connections.[3]

[3]A natural question is whether firms tried to escape labor market conflict by substituting other inputs for labor or relocating their production. In fact, many firms in the Rust Belt did try to escape labor market conflict by substituting capital for labor (see e.g. Serrin, 1973; Meyer, 2004). However, organized labor generally resisted these attempts, and explicitly limited capital-labor substitution as part of their collective bargaining agreements (Strohmeyer, 1986; Rose, 1998; Barnard, 2004; Steigerwald, 2010). Firms did also attempt to escape conflict by re-locating their production outside of the Rust Belt. For example, the auto industry developed a relocation plan that was known as the "Southern Strategy" in the 1960s and 1970s, which involved moving auto production to southern states where unions were less prevalent. However, this approach did not achieve what management had hoped. Nelson describes that "the UAW was able to respond (to the Southern Strategy) by maintaining virtually 100 percent organization of production workers in all production facilities" (see Nelson (1996), p 165).

2.4. Changes of the 1980s

The three facts described above – the secular decline in the Rust Belt's manufacturing employment share, its high rates of labor conflict, and its wage premium – all 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 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.

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

The change in labor relations is seen clearly in Figure 3, which shows the number of major work stoppages per year from the end of World War II through 2000. The figure shows that the number of large strikes declined remarkably around the early 1980s, from several hundred per year before to less than fifty afterwards.

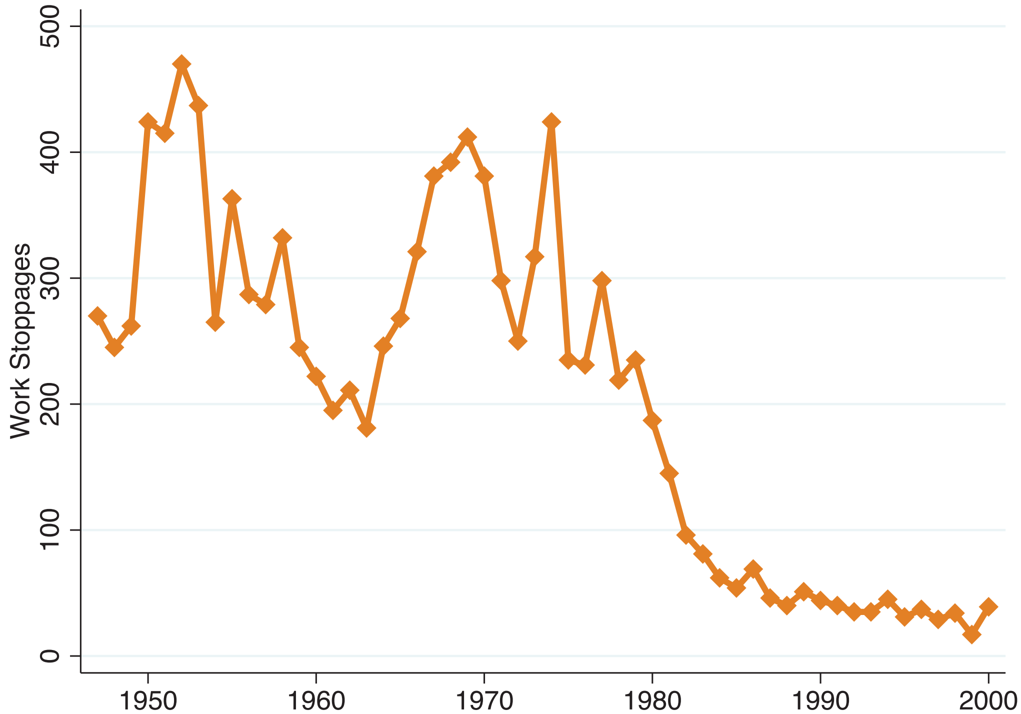
Many studies have analyzed how union bargaining power declined around this time, and much of the literature cites Reagan's 1981 decision to fire striking unionized federal air traffic controllers as a key factor (see McCartin, 1986; Cloud, 2011, and the references therein). Academic studies, as well as the views of industry participants, conclude that the firing of the air traffic controllers and the decertification of their union led to much wider use of permanent replacement workers during strikes, which in turn reduced union bargaining power and the effectiveness of the strike threat.

While data on conflict by region and industry are not available after 1980, the fact that the vast majority of work stoppages were in the Rust Belt manufacturing industries before 1980 suggests that the largest decline in work stoppage rates must have been in Rust Belt manufacturing.[4]

Consistent with the theory that the Rust Belt's wage premia were related to their labor conflict, the decline in worker bargaining power coincides with the declining wage pre-

[4]Direct evidence also suggests that this is the case. For example, Clark (1982), Hoerr (1988), Kochan, Katz, and McKersie (1994) and Strohmeyer (1986) describe how management and unions in autos and steel changed their bargaining relationships in the 1980s, including changing work rules that impeded productivity growth, in order to increase the competitiveness of their industries. Similarly, the United Steelworkers President Lloyd McBride described steel industry labor relations in 1982 as follows: "The problems in our industry are mutual between management and labor relations, and have to be solved. Thus far, we have failed to do this" (see Hoerr, 1988, page 19).

Figure 3: Major Work Stoppages in the United States



Note: This figure plots the number of work stoppages in the United States affecting 1,000 or more workers each year from 1947 to 2000.

mium. As shown in Figure 2, the wage premium we estimate for Rust Belt manufacturing workers fell from 13 percent in 1950 to around 5 percent by 2000. We also find 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 education categories.

3. Model of Rust Belt's Decline

This section develops a two-region general equilibrium model of the United States to quantitatively assess the impact of labor conflict on the evolution of the Rust Belt's share of U.S. employment. The model captures several features of the Rust Belt economy, including the chronically conflicted and inefficient labor relations between manufacturing firms and unions described above.

Rust Belt unions bargain with Rust Belt manufacturing firms after firms have already made their investments. Unions are able to raise wages above the competitive wage rate by capturing some of the returns from those investments through a strike threat. This strike threat is a de facto tax on investment, and thus reduces the incentives for Rust Belt firms to invest. This de facto investment tax follows from a large microeconomic literature that has studied labor conflict and investment, and finds that conflict significantly depresses investments in physical capital (Bronars and Deere, 1993; Cavanaugh, 1998; Fallick and Hassett, 1999; Hirsch, 1991) and intangible capital, including R&D spending (Betts, Odgers, and Wilson, 2001; Bronars and Deere, 1993; Connolly, Hirsch, and Hirschey, 1986). Lower investment leads to lower productivity growth and a reallocation of workers into other areas of the country, as in models of structural change of (Ngai and Pissarides, 2007; Herrendorf, Rogerson, and Valentinyi, 2014).

Workers optimally choose their location and sector, given the Rust Belt wage premium, the scarcity of union jobs, and given their union membership status. With the exception of the manufacturing sector in the Rust Belt, labor markets are competitive and workers are paid the competitive wage. International trade is included in the model to evaluate the role of increased foreign competition for goods made primarily in the Rust Belt in the reallocation of manufacturing jobs within the United States.

3.1. Preferences, Technologies, and Geography

Time is discrete and periods are indexed by t. There is a unit measure of workers who each have linear preferences over a single final consumption good:

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

where $0 < \delta < 1$ is the discount factor. There are two regions: the Rust Belt (indexed by r) and the Rest of the Country (indexed by s). Workers are endowed with one unit of labor each period, which they supply inelastically, and choose which region to locate in, as we explain below. For expositional purposes, we drop the time subscript t from now on.

The final consumption good is produced in region $\ell \in \{r, s\}$ from manufactured goods and non-tradeable local services:

$$Y^\ell = \left(\mu \left(Y_m\right)^{\frac{\theta-1}{\theta}} + (1-\mu)\left(Y_n^\ell\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}}, \tag{2}$$

where $0 < \theta < 1$ is the elasticity of substitution between manufactures, Y_m, and local services, Y_n, and $0 < \mu < 1$ is the weight on manufactures. The local service is produced competitively using only labor inputs:

$$Y_n^\ell = Z_n L_n^\ell, \tag{3}$$

where Z_n is the nationwide productivity of the service industry and and L_n^ℓ is the labor input into services in region ℓ. Service productivity grows at a constant exogenous growth rate χ_n in both regions, so that $Z_n' = (1+\chi_n)Z_n$.

The manufactured good is produced competitively and freely traded across regions. It is itself a composite of intermediates indexed by sector $i \in [0,1]$ and variety $j \in [0,1]$. The aggregation from sectoral inputs to the manufactured good uses a CES technology with substitution elasticity σ:

$$Y_m = \left(\int_0^1 y_m^h(i)^{\frac{\sigma-1}{\sigma}} di\right)^{\frac{\sigma}{\sigma-1}}, \tag{4}$$

where $y_m^h(i)$ is the quantity of output from sector i used to produce domestic manufactured goods.

Similar to the models of Atkeson and Burstein (2008) and Edmond, Midrigan, and Xu (2015), we assume that each of the sectors is populated by a continuum of firms producing differentiated varieties. These domestic firms are indexed by $j \in (0,1)$ and there is an analogous unit measure of foreign firms in each sector i:

$$y_m^h(i) = \left(\int_0^1 y_m^h(i,j)^{\frac{\rho-1}{\rho}} dj + \int_0^1 y_m^{*h}(i,j)^{\frac{\rho-1}{\rho}} dj\right)^{\frac{\rho}{\rho-1}}, \tag{5}$$

where $y_m^h(i,j)$ denotes the input quantity of the domestic variety j in sector i and $y_m^{*h}(i,j)$ the quantity of the foreign variety j in that same sector. Note that a given domestic producer (i,j) does not compete head-to-head with a single foreign counterpart. Rather, competition is monopolistic vis-à-vis all domestic and foreign producers in industry i. We adopt the standard notation from the trade literature where asterisks (*) denote the location of production and $\{h, f\}$ index the location of use. Moreover, we follow Atkeson and Burstein (2008) and Edmond, Midrigan, and Xu (2015) and assume that $\rho > \sigma$, meaning the substitutability between any two within-sector varieties is higher than between a pair of intermediates in two different sectors.

Each intermediate good is produced by a single firm using the linear technology:

$$y_m(i,j) = z_m(i,j) l_m(i,j), \tag{6}$$

where $z_m(i,j)$ is the domestic firm's productivity and $l_m(i,j)$ is the labor input chosen by the firm. Each firm takes its own productivity and the productivities of all other firms in the current period as given. The productivities of domestic manufacturing firms evolve endogenously and we describe this innovation process in Section 3.6 below.

The two regions host distinct manufacturing sectors. In particular, the sectors indexed by $i \in (0, \lambda]$ are located in the Rust Belt, and those indexed by $i \in (\lambda, 1]$ are located in the Rest-of-Country. These regions differ in the nature of competition in their labor markets, which we describe shortly.

For simplicity, we restrict our attention to symmetric equilibria where domestic productivities are equalized *within* regions and hence take on one of two values, z_m^r and z_m^s. Put differently, z_m^r denotes the productivity of firms that produce intermediate goods in sectors indexed by $i \in (0, \lambda]$, i.e. those in the Rust Belt, and z_m^s the productivity of those firms in sectors indexed by $i \in (\lambda, 1]$.

3.2. Foreign Sector and Trade

Let $z^*(i,j)$ denote the productivity of a foreign firm producing intermediate good (i,j). Analogously to production at home, a single foreign manufacturing firm produces a variety j in sector i abroad using the technology:

$$y_m^*(i,j) = z_m^*(i,j) l_m^*(i,j). \tag{7}$$

To mirror the domestic economy, foreign productivities are z_m^{r*} and z_m^{s*} in regions r and s, respectively. In contrast to the endogenous innovation decisions at home, the productivities of foreign manufacturers evolve exogenously, for simplicity, at rates χ_m^{r*} and χ_m^{s*}, so that $(z_m^{r*})' = z_m^{r*}(1+\chi_m^{r*})$ and $(z_m^{s*})' = z_m^{s*}(1+\chi_m^{s*})$.

All intermediate manufactured goods can be traded domestically at no cost and internationally at an iceberg-style cost $\tau \geq 1$. Lastly, we require trade to be balanced each period. This simplification enables us to maintain rich features elsewhere in the model without substantively affecting our quantitative findings.

3.3. Labor Markets and the Union

The structure of labor markets differs by region. In the Rust Belt, labor markets in the manufacturing sector are governed by a labor union, while they are perfectly competitive elsewhere. Each worker's status is either "non-union" or "union member". We assume that the cost of moving workers across space is zero. However, only union members can be hired by Rust Belt manufacturers. Non-union workers can work in either of the two non-traded sectors or in Rest-of-Country manufacturing, or they can attempt to get hold of a manufacturing job in the Rust Belt by applying for union membership. Any non-union worker choosing to locate in the Rust Belt faces a (time-varying) probability F of being offered a union card and hence the opportunity to take a union job. The rate F is a function of the state, though we write it as a number here for convenience.[5] If the worker ends up with a union job, she earns the union wage and becomes a union member. With probability $1 - F$ she does not find work in Rust Belt manufacturing, remains non-union, and, in addition, incurs a disutility $\bar{u}$ of having queued unsuccessfully.

Union membership is an absorbing status but each period an exogenous fraction ζ of all workers retires and is replaced with an identical measure of new workers, who enter with non-union status. This parsimonious life-cycle specification of the workforce allows us to specify the workers' location decisions in a convenient way, given that union jobs are rationed. Let U denote the unionization rate in a particular period, i.e. the measure of unionized workers, and let M be the (endogenous) fraction of non-union workers that choose to locate in the Rust Belt. The law of motion for unionization is given by:

$$U' = (1 - \zeta)[U + MF(1 - U)], \tag{8}$$

so that next period's aggregate unionization rate is the measure of union members who didn't retire plus the measure of (formerly non-union) workers who chose to locate in the Rust Belt, apply for a union card, and were granted membership in the current period.

Non-union workers receive the competitive wage each period, which we normalize to unity. Union workers are paid the competitive wage plus a union rent, which is a share of the profits of manufacturing firms in the Rust Belt. We assume that profits are split each period between each Rust Belt manufacturer and its unionized labor force according to a Nash bargaining protocol, as in the bargaining model of Grout (1984). This assumption provides a simple way of capturing the persistent holdup problem that characterized Rust Belt labor relations for decades.

The parameter β is the union's Nash bargaining weight, which takes on one of two values: β_H or β_L, where $\beta_H > \beta_L > 0$. We initiate the economy with bargaining power β_H, which we take to represent the period right after the end of World War II. Each period, the

[5]One can think of the application process as a queuing problem – since union jobs are rationed – with random selection if Rust Belt jobs cannot be filled with current union members. F is the probability of selection and it equals the ratio of open jobs to the length of the queue.

probability of transitioning to β_L is given by $\epsilon \in (0,1)$. The β_L state is absorbing. The stochastic specification for the evolution of this state variable captures the fact that Rust Belt industry participants anticipated an erosion of the union's bargaining power, but were uncertain about the timing (Clark, 1982; Serrin, 1973).

Crucially, unions cannot commit to refrain from bargaining over post-innovation profits generated by an individual intermediate good producer once the cost of innovation is sunk. The outside options of the union workers and firm are as follows. If the strike is successful and the firm does not produce for one period, the profits are zero. If the strike fails, the workers are paid the competitive wage. That is, they do not receive any share of the firms profit Π_m^r. Formally, the union solves:

$$b^* = \arg\max_b \big(b\Pi_m^r\big)^{\beta}\big((1-b)\Pi_m^r\big)^{1-\beta},$$

which has the standard solution $b^* = \beta$. Put differently, the union extracts $\beta\Pi_m^r$ each period and the firm keeps $(1-\beta)\Pi_m^r$. This bargaining outcome will appear again in the firm's innovation problem, which we characterize in Section 3.6.

3.4. Static Final-Good Producers' Problem

The static problem of final-good producers is standard but nonetheless important for understanding the model's mechanisms. Final-good producers choose inputs of the domestic and foreign manufacturing varieties and local services to maximize static profits:

$$\max_{\{y_m^{h,r}, y_m^{h,s}, y_m^{h,r*}, y_m^{h,s*}, Y_n\}} P\left(\mu\left(Y_m\right)^{\frac{\theta-1}{\theta}} + (1-\mu)\left(Y_n\right)^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}} - \sum_{\ell\in r,s}(y_m^{h,\ell}p_m^{h,\ell} + y_m^{h,\ell*}p_m^{h,\ell*}) - P_nY_n, \tag{9}$$

where P is the price of the final good; p_m^r and p_m^s are the prices of the domestic intermediates from the Rust Belt and rest of country; and p_m^{r*} and p_m^{s*} are the prices of the foreign intermediates. The manufacturing aggregate Y_m is defined as:

$$Y_m = \left[\lambda(y_m^r)^{\frac{\sigma-1}{\sigma}} + (1-\lambda)(y_m^s)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{\sigma-1}}, \tag{10}$$

and the sectoral aggregates y_m^ℓ are defined in turn, for $\ell \in \{r,s\}$, as:

$$y_m^\ell = \left((y_m^{h,\ell})^{\frac{\rho-1}{\rho}} + (y_m^{h,\ell*})^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}}. \tag{11}$$

Several equilibrium features of the model are noteworthy. First, the final-goods price, P, is the same across regions. The same is true for the price of services, P_n. The reason is that the manufactured good is freely traded across regions and services have the same productivity in both regions. Second, the share of total expenditures on manufactured goods, which we denote ν, depends only on μ, θ and relative prices (see equation (24)).

Third, and most importantly, because of the CES structure in equation (10), together with the elasticity of substitution σ being greater than one, the final-goods producer will respond to a higher price of one region's intermediates by substituting to intermediates from the other region. Similarly, the final-goods producer will respond to a price increase by a domestic variety, holding all else constant, by substituting toward the foreign variety. These features are important for understanding the dynamics of the regional manufacturing employment shares, as we discuss further below.

3.5. Static Intermediate Firms' Problem

For domestic intermediate firms, the static component of their problem is standard. For a domestic intermediate producer in region ℓ, the firm's static problem is to maximize current-period profits by choosing output prices, output and labor inputs for domestic consumption and exports, subject to the demand curves for the firm's output and the production function:

$$\Pi_m^\ell = \max_{\{p_m^{h,\ell},\, p_m^{f,\ell},\, l_m^{h,\ell},\, l_m^{f,\ell},\, y_m^{h,\ell},\, y_m^{f,\ell}\}} \Big\{ p_m^{h,\ell} y_m^{h,\ell} + p_m^{f,\ell} y_m^{f,\ell} - l_m^{h,\ell} - l_m^{f,\ell} \Big\}, \tag{12}$$

subject to

$$\begin{aligned} y_m^{h,\ell} &= z_m^\ell l_m^{h,\ell}, \\ y_m^{f,\ell} &= z_m^\ell l_m^{f,\ell}, \\ y_m^{h,\ell} &= P_m^{\sigma-1} (P_m^\ell)^{\rho-\sigma} \nu (X^r + X^s) \big(p_m^{h,\ell}\big)^{-\rho}, \\ y_m^{f,\ell} &= (P_m^*)^{\sigma-1} (P_m^{*\ell})^{\rho-\sigma} X^* \big(\tau p_m^{f,\ell}\big)^{-\rho} \tau. \end{aligned} \tag{13}$$

Here $p_m^{h,\ell}$ and $p_m^{f,\ell}$ denote the prices charged per intermediate good in the domestic and foreign markets; $y_m^{h,\ell}$ and $y_m^{f,\ell}$ are the quantities of the intermediate good produced for the domestic market and for export; and $l_m^{h,\ell}$ and $l_m^{f,\ell}$ are the labor inputs used in production. The first two constraints are the production functions (for the home and export market, respectively) and the next two are the firm's demand functions for domestic sales and exports. X^r and X^s are values of total expenditures in regions r and s. P_m^ℓ is the sectoral price index for intermediates coming from regions $\ell \in \{r, s\}$. Asterisks denote the corresponding price indices and aggregate expenditure abroad.

The firm's optimal factory-gate price is the standard Dixit-Stiglitz monopolist markup, regardless of destination:

$$p_m^{h,\ell} = \tfrac{\rho}{\rho-1}\tfrac{1}{z_m^{\ell}} = p_m^{f,\ell}. \tag{14}$$

This destination-independence result is standard in the literature and stems from the linearity of the production function. In essence, manufacturing firms solve two distinct and independent optimization problems for domestic sales and exports. Since domestic labor is the numeraire and the optimal price is a constant markup over marginal cost for all producers abroad, aggregate expenditures in the Rest-of-the-World are given by

$$X^* = \tfrac{\rho}{\rho-1}w^*, \tag{15}$$

where the foreign wage, w^*, is a non-linear function of the aggregate state. We derive its equilibrium value, and other equilibrium prices, in Appendix B. The foreign manufacturing firms set the same markup as domestic firms over their marginal cost:

$$p_m^{h,\ell*} = \tfrac{\rho}{\rho-1}\tfrac{w^*}{z_m^{\ell*}}. \tag{16}$$

Note that all the endogenous variables described in this section are functions of state variables, but we refrain from writing it this way for expositional purposes.

3.6. Intermediate Firms' Dynamic Problem

In addition to the static production problem, manufacturing firms engage in innovation, which raises their future productivity but requires an investment in units of the final good today. We have a broad notion of investment in mind, which includes anything that increases labor productivity, such as new technologies embodied in capital equipment.

To write the intermediate firms' problem, it is useful to define $Z \equiv \{z_m^r, z_m^s, z_m^{r*}, z_m^{s*}, Z_n\}$. The variable Z is a state variable in the problem of any individual firm, and includes the set of all productivities across foreign and domestic manufacturing firms and the service sector. The measure of union workers U is also a state variable. Unlike in the static problems above, we express the firms' dynamic problem with the final good price as a function of the state: $P(Z, U; \beta)$.

We assume that for a firm with productivity level z, increasing productivity by x percent requires $C(x, z, Z)$ units of the final good. The function $C(x, z, Z)$ captures the cost of investment. We assume that it is convex in x and depends on the firm's own productivity as well as other firms in the economy (both at home and abroad). Firms purchase each unit of the final good at price $P(Z,U;\beta)$. The law of motion for the firm's idiosyncratic productivity is $z' = z(1+x)$. We describe our functional form for $C(x, z_m, Z)$ in Section 3.7 below.

The manufacturer's dynamic problem depends on the region to which it belongs. Let z be the productivity of a particular intermediate firm in the Rest-of-Country. The dynamic problem is given by the following Bellman equation:

$$V^s(Z,U,z;\beta) = \max_{x^s>0} \big\{\Pi_m^s(Z,U,z;\beta) - P(Z,U;\beta)\cdot C(x^s,z,Z) \\ +\delta E[V^s(Z',U',z';\beta')]\big\}, \quad (17)$$

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

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

$$V^r(Z,U,z;\beta) = \max_{x^r>0} \big\{(1-\beta)\Pi_m^r(Z,U,z;\beta) - P(Z,U;\beta)\cdot C(x^r,z,Z) \\ +\delta E[V^r(Z',U',z';\beta')]\big\}, \quad (18)$$

where $z' = z(1+x^r)$ and the perceived law of motion for Z is, again, $Z' = G(Z,U;\beta)$. Note that the productivity of any individual firm, z, is potentially different from the productivities of other firms in the same region, in equilibrium, however, they will be the same.

In contrast to firms located in the rest of the country, Rust Belt manufacturers keep only a fraction $1-\beta$ of each period's profits. As we discuss further below, this feature captures the hold-up problem, which is modeled as an atemporal Nash bargaining protocol between the firms and their unionized workforce. The hold-up problem works like a tax on investment, and depresses investment and productivity growth for Rust Belt manufacturers.

3.7. Investment Cost Function

We select a functional form for the cost function that has several desirable properties. First, the cost of investment is increasing and convex in the amount of innovation, x.

Second, the function has a parsimonious number of parameters. Third, the cost function has a degree of homogeneity such that the optimal innovation decision on individual firm does not depend on the scale of the productivities.

Homogeneity of degree zero allows us to express all productivities relative to a benchmark producer, which we choose to be a Rest-of-Country manufacturing firm. More specifically, this is equivalent to requiring that the cost of innovation in units of the numeraire, $P(Z, U; \beta) \cdot C(x, Z, z)$, be homogeneous of degree zero with respect to all the productivities. The lack of scale effects has a long tradition in the growth literature (see e.g. Jones, 1995) and it guarantees that we can solve the firms' dynamic programs using standard techniques.

As we show in Appendix B, a cost function that satisfies these requirements is:

$$C(x, Z, z) = \alpha x^{\gamma} \frac{z^{\rho-1}}{\mathcal{Z}}, \tag{19}$$

where the denominator, $\mathcal{Z}$, is a function of the productivity of other firms in the economy:

$$\mathcal{Z} = \left(\lambda\left(z_m^r\right)^{1-\sigma} + (1-\lambda)\left(z_m^s\right)^{1-\sigma}\right)^{\frac{2-\rho}{1-\sigma}}.$$

The parameters α and γ govern the scale and curvature of the cost function. While these parameters are abstract, we show below that they can be disciplined using the long-run growth rate of the economy and the long-run average share of GDP spent on innovation.

3.8. Workers' Problem

To characterize the worker's problem we need to introduce some additional notation. Let D denote the per capita dividend paid by a fully diversified mutual fund and let R be the par capita union rent of a worker employed by a Rust Belt manufacturing firm. Then, the worker's income (and hence her expenditures) are given by:

$$E_m^r = w + D + R, \text{ and} \tag{20}$$

$$E_k^{\ell} = w + D, \quad \text{for } (\ell, k) \in \{(r, n), (s, m), (s, n)\}. \tag{21}$$

Since firms in the non-tradeable sector generate zero profits, aggregate profits and hence dividends are simply a function of manufacturing profits in (12):

$$D = \lambda(1-\beta)\Pi_m^r + (1-\lambda)\Pi_m^s, \tag{22}$$

where we have suppressed the dependence on aggregate state variables for simplicity. Since the population is of measure one, D denotes aggregate profits as well as per capita dividends. R is the rent extracted by the union in the bargaining process divided evenly across card-carrying workers, that is:

$$R = \beta\Pi_m^r/(l_m^{r,h} + l_m^{r,f}). \tag{23}$$

Since Rust Belt manufacturing jobs pay a premium R, but are also in limited supply, workers must decide where to locate each period, so as to maximize expected discounted utility. Since there is no intertemporal consumption-saving decision, this is equivalent to maximizing the expected present value of income (and hence expenditures). Thus, the worker's problem is easy to characterize. As long as union rents are positive, union members will strictly prefer to locate in the Rust Belt. In contrast, non-union workers will be indifferent between locating in the two regions only for one particular job finding rate, all else equal. Following previous spatial models, such as the model of Desmet and Rossi-Hansberg (2014), we focus on an equilibrium where (non-union) workers are indifferent across locations. In Appendix B we spell out the worker's dynamic problem formally.

3.9. Discussion: Regional Employment Dynamics

While the model does have an analytical solution, the regional employment dynamics at the heart of the paper can be characterized conditional on investment decisions. Here we discuss these dynamics, and the role of regional investment differentials and foreign productivity growth on the Rust Belt's manufacturing employment.

Suppose that manufacturing firms in the Rust Belt decide to invest less in some period than their counterparts in the rest of the country, i.e. $x^r < x^s$. How does this affect employment in the Rust Belt in the following period? By the laws of motion for the firms' problems in (17) and (18), productivity will rise faster for firms in the rest of the country than in the Rust Belt. Since all manufacturing firms charge a standard monopolist markup above cost (equation (16)), the price of manufactured goods produced in the rest of the country will fall relative to the prices of Rust Belt goods. The final-good producers will then demand fewer of the Rust Belt goods, as described in Section 3.4. Since production functions are linear in labor, demand for labor in the Rust Belt will fall. This is the same mechanism as in Ngai and Pissarides (2007), in the case where goods are gross substitutes.

A separate force affecting regional employment dynamics is foreign productivity growth. Consider the case where the productivity growth is faster for goods similar to those produced in the Rust Belt than for other manufactured goods, which we can capture in the model with $\chi_r^* > \chi_s^*$. Through competition, this will lead to a fall in the price of "foreign Rust Belt goods" relative to other foreign manufactured goods. Similar to the discussion in Section 3.4, this will lead domestic final-goods producers, all else equal, to demand more of the former and less of the domestic manufactured goods produced in the Rust Belt. This will also lead to a decline in the demand for labor in the Rust Belt's manufacturing sector.

The strength of these two channels ultimately depends on a number of model parameters, including the elasticities of substitution, the strength of the hold-up problem in investment and the foreign productivity growth rates. In the following section we turn to a quantitative analysis of the model.

4. Quantitative Analysis

This section presents a quantitative analysis of the model to assess how much of the employment share decline from 1950-2000 can plausibly be accounted for by labor market conflict in the Rust Belt and foreign productivity growth patterns. We calibrate the differences in labor market competition between the Rust Belt and the Rest-of-Country using the evidence on wage premiums we presented in Section 2, and foreign productivity growth using U.S. import shares by industry. We find that the calibrated model accounts for around 70 percent of the observed drop in the Rust Belt's manufacturing employment share.

4.1. 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 across industries we set $\sigma = 2.7$, based on the work of Broda and Weinstein (2006), who estimate elasticities of substitution between a large number of goods and find median elasticities between 2.7 and 3.6, depending on the time period and degree of aggregation. We set the elasticity of substitution between varieties to $\rho = 2.8$, which is also in the range suggested by Broda and Weinstein (2006), and larger than σ, as assumed in our model. We show below that both of these choices are

Table 2: Parameters Used in the Quantitative Analysis

Moment	Value
Directly Targeted	
δ – discount factor (five-years)	0.82
σ – elasticity of substitution between sectors	2.70
ρ – elasticity of substitution between varieties	2.80
θ – elasticity of substitution between Y_m and Y_n	0.10
ϵ – probability of transition to more competitive state	0.17
Jointly Targeted	
λ – share of sectors in Rust Belt	0.51
γ – curvature term in cost function	1.59
α – linear term in cost function	0.41
μ – weight on manufacturing	0.001
χ_s^* – foreign s productivity growth rate	0.12
χ_r^* – foreign r productivity growth rate	0.15
χ_n – service productivity growth	0.01
τ – trade costs	4.99
β_h – labor bargaining in high-distortion state	0.36
β_l – labor bargaining in low-distortion state	0.12
$z_{r,0}^*$ – initial foreign r productivity level	0.38

Note: This table reports the parameter values used in the benchmark quantitative analysis. The first five values are targeted directly. The next eleven parameters are calibrated jointly, as described in the text.

likely to be conservative, in the sense that larger values predict even larger declines of the Rust Belt than our benchmark calibration. We pick the elasticity of substitution between manufacturing and services to be $\theta = 0.1$ consistent with the findings of Herrendorf, Rogerson, and Valentinyi (2014) and Garcia-Santana, Pijoan-Mas, and Villacorta (2016), who estimate this elasticity to be near zero. In terms of initial conditions, we set $z_{S,0} = z_{R,0} = z_{S,0}^* = 1$, though we have found that our results are not sensitive to these values given our calibration strategy. We set the five-year transition probability for β to $\epsilon = 1/6$, corresponding to six model periods in the initial high state, or 30 years, in expectation.

We calibrate the remaining eleven parameters to jointly match eleven moments in the data. The parameters to calibrate are: (i) λ, the share of goods produced in the Rust Belt, (ii and iii) γ and α, the curvature and linear terms in the investment cost function, (iv) μ, the weight on manufacturing relative to services in the aggregate production function, (v and vi) χ_s^* and χ_r^*, the foreign productivity growth rates, (vii) χ_n, the productivity growth rate in non-tradeable services, (viii) τ, the iceberg trade cost, (ix and x) β_H and β_L, the labor bargaining terms pre- and post-1980, and (xi) $z_{R,0}^*$, the initial foreign Rust Belt productivity level.

Table 3: Moments Targeted: Model vs Data

Moment (%)	Model	Target
Initial employment percent of Rust Belt	51.3	51.3
Innovation as a percent of GDP	7.0	7.0
Long-run annual GDP growth rate	1.8	1.8
Manufacturing share of aggregate employment, 1950	30.2	30.2
Manufacturing share of aggregate employment, 2000	12.9	12.9
Rust Belt import share, 1958	4.5	4.5
Rust Belt import share, 1990	58.6	58.6
Aggregate import share, 1950	3.0	3.0
Aggregate import share, 2000	12.3	12.3
Rust Belt wage premium, 1950-1980 average	12.0	12.0
Rust Belt wage premium, 1980-2000 average	4.0	4.0

Note: This table reports the eleven moments targeted in the calibration and their values in the calibrated model.

The eleven moments we target are: (i) the initial employment share of 51.3 percent in the Rust Belt, corresponding to the actual share in 1950; (ii) an average innovation investment-to-GDP ratio of 7.0 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); (iii) a long-run output growth rate of 1.8 percent per year; (iv and v) manufacturing employment shares of aggregate employment in 1950 and 2000 of 30.2 percent and 12.9 percent; (vi and vii) Rust Belt import shares of 4.5 percent in 1958, and 58.6 percent in 1990; (viii and ix) aggregate import shares of 3 percent in 1950 and 12.3 percent in 2000; (x and xi) the Rust Belt wage premium of 12 percent and 4 percent pre- and post-1980, as in Figure 2.

Table 2 reports the value of each parameter used in the calibration. The model matches the desired moments quite well, and in all cases to the second decimal place. For completeness we report each moment and its model counterpart in Table 3. While all moments above jointly discipline all the parameters, it is useful to provide some intuition about which moments are most informative about each parameter. The initial employment share in the Rust Belt, (i), is most informative about λ, since λ controls the fraction of goods produced in the Rust Belt. The investment-to-output ratios and long-run growth rates, (ii) and (iii), are most informative about the scale and curvature terms in the cost function, α and γ. The aggregate import shares largely govern the trade cost, τ, the initial foreign Rust Belt productivity, $z^*_{r,0}$ and the foreign productivity growth rates. The manufacturing shares of aggregate employment are largely governed by the weight on manufacturing, μ, and the service productivity growth rate, χ_n. The Rust Belt wage premia largely govern the worker bargaining power, β_H and β_L.

4.2. Quantitative Predictions

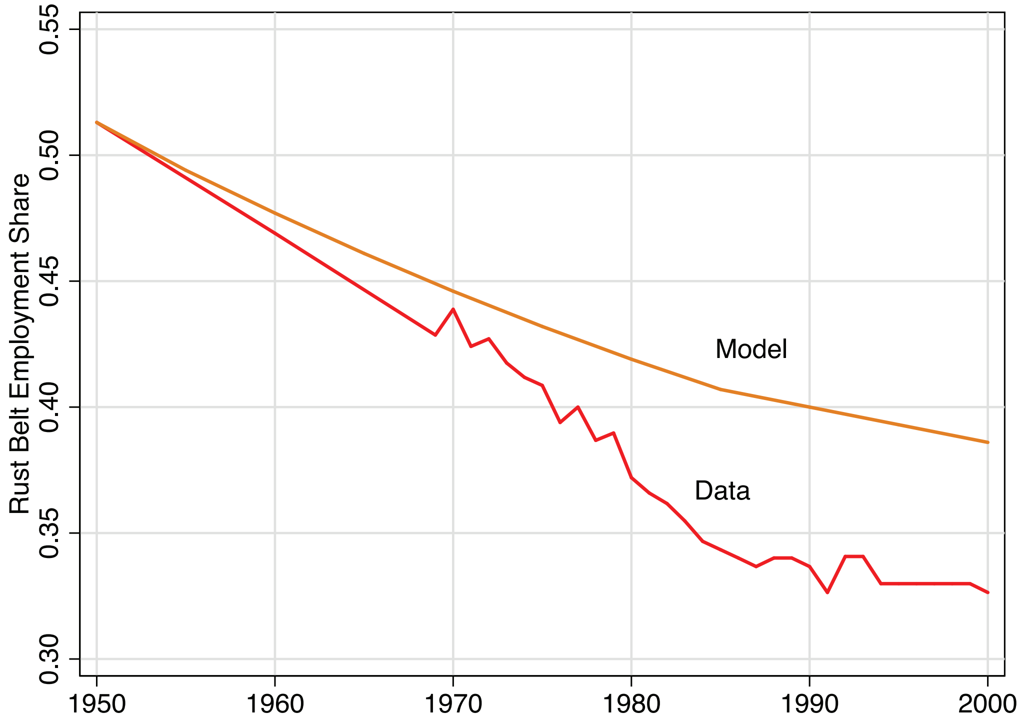
With the model parameters calibrated, we compute the equilibrium of the model and solve for the evolution of regional employment shares, productivity growth rates, and other endogenous variables, given the transition probability of the unions bargaining power, β, as described above. Ex-post, we impose that the state switches from β_H to β_L in 1985. We impose this shift in the state in 1985 to be consistent with the decrease in labor bargaining power observed in the data, as described in Section 2.

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. This decline is simply the natural evolution of lower investment and lower productivity growth that follows from the union hold-up problem. Overall, the model predicts a drop of 12.7 percentage points, compared to 18.3 percentage points in the data. Thus, the model accounts for around 70 percent of the overall decline in the data.

A second feature of Figure 4 worth noting is that the model's predicted decline is more pronounced between 1950 and 1985 than in later years, and that, again, mirrors the slope of the decline in the data. The model predicts a drop of 10.6 percentage points until 1985, compared to a 14.3 percentage point drop in the data. After 1985, the model predicts a further 2.1 percentage-point drop in the employment share, compared to a 2.5 percentage-point decline in the data. Why does the model predict a steeper decline in the earlier period? The reason is that the hold-up problem depresses investment in the Rust Belt relatively more in the period before 1985, since union bargaining power is greater then ($\beta_H > \beta_L$). Afterwards, the lower bargaining power reduces the hold-up problem, which helps arrest the decline in the Rust Belt's share of employment.

Figure 5 displays the aggregate and Rust-Belt import shares in the model and data. The green solid line is the average import share in the Rust Belt's import share, which we com-

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



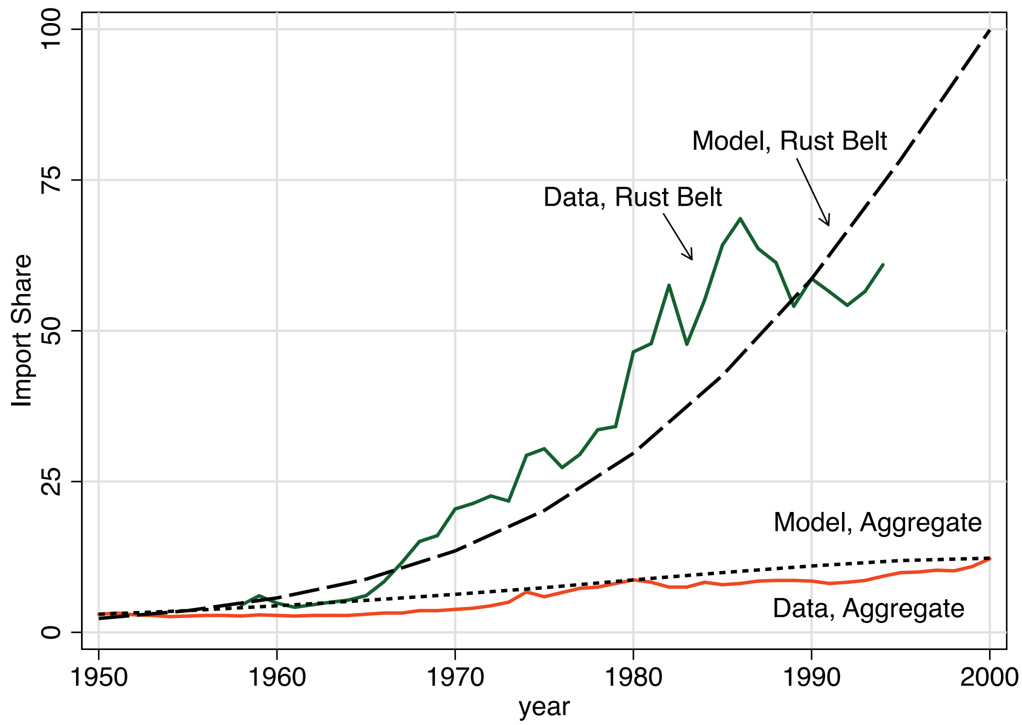
Note: This figure plots the share of U.S. manufacturing employment located in the Rust Belt (solid red line) and the model's prediction for this share (orange line).

pute as a weighted average of import shares for the top twenty industries by employment concentration in the Rust Belt, using the industry-level import data of Feenstra (1996) and industry-level value added data from the NBER CES database. The red solid line is the aggregate import share, which we acquired from FRED. The model's calibrated import shares in the model are displayed in Figure 5 as the two dashed lines. While stylized, our model does match the data on imports fairly well, as per the calibration strategy, in particular the much larger increase in import shares in the Rust Belt then in the aggregate economy.[6]

Figure 6 plots the model's share of aggregate services employment and the same share in the data. The model is parameterized to match the service shares in 1950 and 2000 and reproduces the approximately linear trend quite well. While we do not target rela-

[6] Autor, Dorn, and Hanson (2013a) document that regions in U.S. industries that were more exposed to imports from China since 1990 experienced substantially worse labor market outcomes relative to other regions. Since imports from China were only 2 percent in 1990 and negligible before that, imports from China are quite unlikely to have played an important role in the Rust Belt's decline from 1950 to 1990. Furthermore, most of the affected regions were located outside the Rust Belt (see Autor, Dorn, and Hanson, 2013b, Figure 1B).

Figure 5: Import Shares: Model and Data



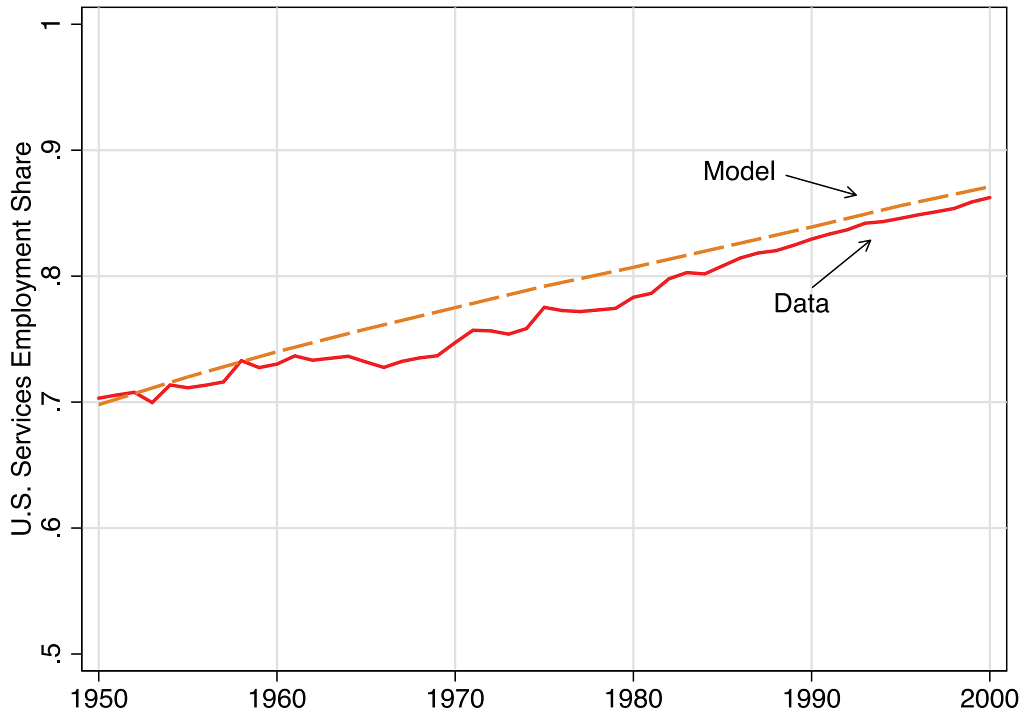
Note: This figure plots import shares in the aggregate U.S. economy (green line) and in the industries most prevalent in the Rust Belt (red line), plus the model's predictions for each (short and long dashed black lines). Import shares are defined as imports divided by total industry value added and come from Feenstra (1996).

tive manufacturing productivity growth rates in our calibration, the model is consistent qualitatively with the data. The model predicts that the Rust Belt's average annual productivity growth rate was 0.7 percentage points below the rest of the country before 1985. Afterwards, the gap narrowed to 0.2 percentage points. In the data, industries predominant in the Rust Belt had 0.6 percentage points lower annual growth than industries most predominant outside the Rust Belt before 1985. Afterwards, the growth rate of Rust Belt industries was even higher than in other industries.[7]

Several other features of the Rust Belt's economy in the model are consistent with the data. The regional investment-to-GDP ratios, which are not targeted directly, are 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 5.0 percent in the Rust Belt and 8.7 percent in the rest of the country. This

[7] Some of productivity reversal of the 1980s may have come from improved work practices and reduction in union work rules, neither of which we model explicitly. See Schmitz (2005) and Dunne, Klimek, and Schmitz (2010) for evidence of reductions in union work rules raised productivity in the iron ore and cement industries around this period.

Figure 6: Services Share of Aggregate Employment: Model and Data



Note: This figure plots the share of U.S. workers employed in the service industry (red line) and the model's prediction for this share (orange dashed line).

sizable difference in investment rates is due to the lower innovation rates in the Rust Belt industries together with the curvature of the investment cost function. The lower investment rate of the Rust Belt is broadly consistent with the consensus that Rust Belt industries lagged behind the rest of the country.[8]

4.3. Decomposition of Rust Belt's Decline

We now decompose the model's predicted decline of the Rust Belt into three separate channels: (1) labor-market conflict, and its associated hold-up problem, (2) the rise in foreign comparative advantage in Rust Belt goods since 1950, and (3) the initial productivity advantage of Rust Belt firms in 1950. When all three of these channels are shut down, the employment share of the Rust Belt stays exactly constant over time. When one ore more

[8]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 (see e.g. Oster, 1982). Similar evidence can be found for the rubber industry (Rajan, Volpin, and Zingales, 2000) and for the automobile industry (see e.g. Adams and Brock, 1995).

of them is present, the share evolves over time, and the counterfactual simulations we consider in this section help illustrate how.

We focus on two counterfactual simulations. In the first, we shut down both labor market conflict and the rise in foreign comparative advantage in Rust Belt goods, leaving only the Rust Belt firms' initial productivity advantage. We do this by setting $\beta_H = \beta_L = 0$, which removes the hold-up problem, and by setting $\chi_r^* = \chi_s^*$, which equates the foreign productivity growth rate across sectors. We then re-solve the model over the period in question leaving all other parameters the same.

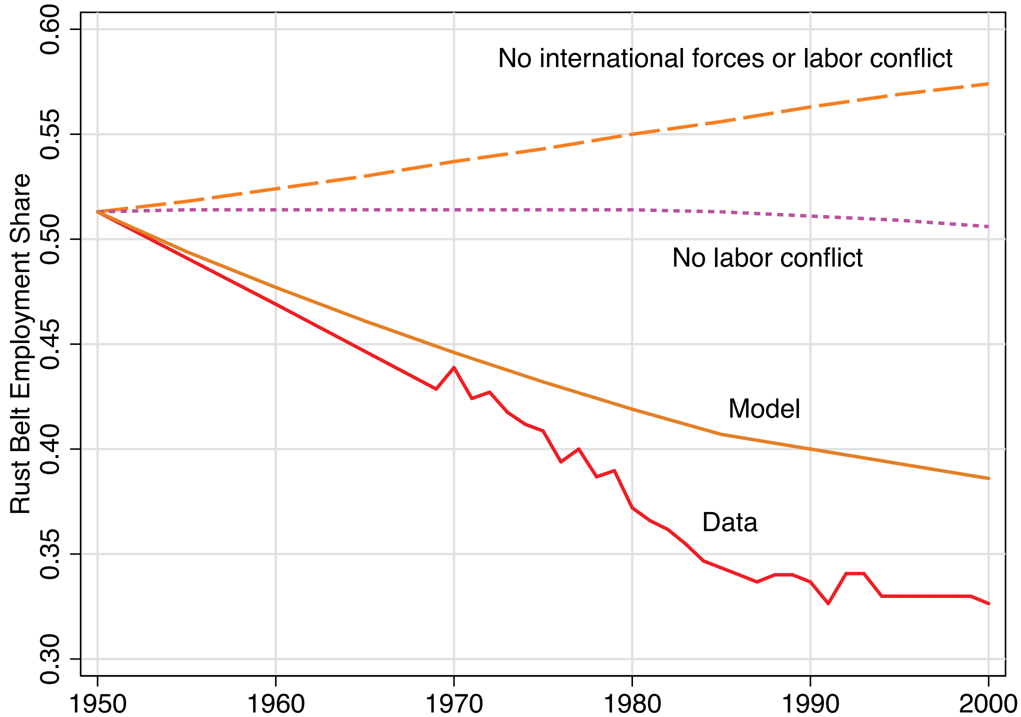
The result of the first counterfactual is depicted as the dashed orange line on Figure 7 labeled "No international forces or labor conflict." In this counterfactual, the Rust Belt's share of employment *rises* by 6.1 percentage points to 57.4 percent. The reason is that the initial productivity advantage of the Rust Belt firms' leads to a market-size effect, standard in models of innovation, that allows Rust Belt firms to spread the fixed cost of investment over more units of output sold. As such, the Rust Belt firms invest relatively more and increase their market share even further over this period.[9]

In the second counterfactual simulation, we add back the rise in foreign comparative advantage but keep the labor-market-conflict channel shut down. That is, we keep $\beta_H = \beta_L = 0$ but return χ_r^* and χ_s^* to their values in the main calibration, in which $\chi_r^* > \chi_s^*$. The result is plotted as the short-dashed purple line in Figure 7 labeled "No labor conflict." In this counterfactual, the Rust Belt's employment share stays approximately constant over this period, falling a modest 0.7 percentage points to 50.6 percent. The international forces by themselves serve to move economic activity out of the Rust Belt, as consumers substitute foreign substitutes for Rust Belt goods, trading for goods made in the rest of the country. Overall, the international forces more or less wipe out the gains in employment share that result from the initial productivity advantage.

As a frame of reference, the figure also re-produces the predictions from the main calibration, which is equivalent to adding back the labor market conflict channel to the second counterfactual. As mentioned previously the decline in the Rust Belt's employment share is 12.7 percent. As a crude way of gauging the relative importance of the labor conflict and international forces channels, we take the difference between the rise of 6.1 percentage points in the "No international forces or labor conflict" counterfactual and the decline of 12.7 percentage points in the main calibration to get an 18.8 percentage point overall

[9] In the long run, the market-size force is offset by the catch-up force arising from our investment cost function, which gives an advantage to firms behind the frontier. Eventually, the model converges to a balanced growth path with constant regional employment shares.

Figure 7: Decomposing the Rust Belt's Decline



Note: This figure plots the share of U.S. manufacturing employment employed in the Rust Belt in the data (red line), in the benchmark model (orange line) and in two counterfactual simulations. The first counterfactually assumes no international change in comparative advantage and no labor market conflict (dashed orange line). The second counterfactually assumed international change in comparative advantage but not labor conflict (short dashed purple line).

difference (12.7 + 6.1) in the model's predicted employment share. Taking 12.7 divided by 18.8 gives a roughly two thirds share attributed to the labor conflict channel, leaving one third due to international forces. In other words, relative to the counterfactual of no international forces or labor conflict, in which the Rust Belt would have actually increased its share of U.S. manufacturing employment, around two-thirds came from labor market conflict, making it the dominant channel.

4.4. Sensitivity Analysis

We next turn to a sensitivity analysis of the model. We do so largely because a number of the key parameters in the quantitative analysis, such as the elasticities of substitution σ and ρ, do not have a single canonical value in the literature, but rather a range.

We begin by looking at how the model's predicted employment share decline of the Rust Belt varies with a higher value of ρ, the elasticity of substitution between domestic and foreign varieties. This is warranted as this elasticity is at the low end of the range of me-

Table 4: Sensitivity Analysis

Alternative Specification	Rust Belt's Employment-Share Change (%)
Same σ, higher ρ: ($\sigma = 2.7$, $\rho = 3.2$)	-15.6
Higher σ, higher ρ: ($\sigma = 3.1$, $\rho = 3.2$)	-16.7
Lower Innovation/VA target of 6 percent	-9.0
Lower Innovation/VA target of 8 percent	-14.4

Note: This table reports the decline in the Rust Belt's share of U.S. manufacturing employment under alternative parameterizations of the model, as specified in the text. In each case all other parameters are disciplined as described in Section 4.

dian elasticities reported by e.g. Broda and Weinstein (2006). We re-calibrate the model with $\rho = 3.2$, which are closer to the middle of the range of estimates by Broda and Weinstein (2006), and pin down all other parameters to match the same moments as before, as described in Section 4. The first row in Table 4 reports the model's predicted change in the Rust Belt's share of U.S. employment with these higher elasticities of substitution. The model's decline is now 15.7 percentage points rather than 12.7 in the benchmark model, meaning that the model explains around 86 percent of the decline observed in the data, up from 70 percent in the benchmark model.

We next ask how the model behaves when the elasticity of substitution between industris, σ, is raised in addition to ρ. Specifically, we keep $\rho = 3.2$ as in the previous sensitivity analysis and set $\sigma = 3.1$, below ρ as assumed in our theory. As shown in the second row in Table 4, in the case the model's decline is 16.7 percent, or 91 percent of the data. We conclude that the model's predictions are sensitive to values for the substitution elasticities σ and ρ, as one would expect. Yet, our benchmark calibration is conservative relative to values used in the literature, and higher values serve to increase the model's predictive power.

The third sensitivity analysis we conduct is with respect to our choice of the innovation share of value added, which affects the size of the hold-up channel in our model. In the calibration, this target is matched largely using the parameter γ, which controls the curvature of the innovation cost function. When we target a value of 6 percent, rather than the 7 percent in our main calibration, the model's predicted decline is 9 percent rather than 12.7 in the main calibration. This implies that the model explains around 50 percent of the data. The fourth sensitivity analysis considers a higher target of 8 percent innovation share of value added. In this scenario the model predicts a decline of 14.4 percent, or 79 percent of the data. Thus, while the model is sensitive to the targeted innovation share of output, it accounts for at least half of the observed decline under any of the targets considered here.

5. Supporting Evidence

This section examines whether our theory's predicted link between labor conflict and employment growth is borne out in disaggregated evidence at the industry-region level. In particular, we ask whether industry-state pairs with more labor conflict had lower rates of employment growth from 1950 to 2000, after including industry fixed effects and state-level controls including initial industry concentration and climate variables. We consider three measures of labor market conflict in turn: major post-war work stoppages, post-war unionization rates, and strikes from 1927 to 1934, which long pre-date the period of employment growth in question. We find that all three measures of conflict are significantly negatively associated with employment growth.

5.1. Work Stoppages from 1958 to 1977

We begin by returning to the data on major work stoppages described in Section 2, which are perhaps the most direct measure of labor conflict available to us. Here, we draw on micro evidence covering all work stoppages from 1958 to 1977 that were recorded by the BLS (U.S. Bureau of Labor Statistics, 1992). We aggregate the data to the state-industry level, so that observations represent e.g. motor vehicles in Michigan or metal mining in Alabama. We then merge the work-stoppage data with census data from IPUMS, state-level temperature and climate statistics, and other variables. The complete description of our data is available in Appendix A.

The outcome of interest is the employment growth rate, measured as the log increase in state-industry employment from 1950 to 2000. Table 5 presents a set of four regressions that explore the correlates of state-industry employment growth rates.

Column (1) regresses state-industry employment growth on the number of major work stoppages per year, the percent of workers that are college educated, and a set of industry fixed effects. The estimated coefficient on major work stoppages turns out to be -0.41, meaning that an additional major work stoppages per year is associated with approximately 50 percent (41 log points) lower employment growth, all else equal. The coefficient is statistically significant at the one-percent level, and economically significant as well: one more work stoppage per year is like moving from two standard deviations

Table 5: Major Work Stoppages and Employment Growth

Independent Vars	(1)	(2)	(3)	(4)
	Dep. Var: Log Employment Growth 1950-2000			
Major Work Stoppages /Year	-0.41***	-0.30***	-0.29***	-0.27***
	(0.071)	(0.063)	(0.058)	(0.056)
Percent College Grad, 1950	0.081	0.076	0.031	-0.0012
	(0.094)	(0.094)	(0.084)	(0.074)
Log State Population, 1950		-0.045***	-0.093***	
		(0.014)	(0.015)	
State Mfg Employent Share, 1950		-1.90***	-1.02***	
		(0.13)	(0.15)	
State Empl. Herfindahl Index, 1950		-2.10***	-1.28***	
		(0.38)	(0.36)	
State Average Temperature			0.013***	
			(0.0026)	
State Std. Dev. Temperature			-0.064***	
			(0.0069)	
State Average Precipitation			-0.014***	
			(0.0013)	
Constant	-1.51***	-0.87***	-0.23	-1.40***
	(0.095)	(0.10)	(0.25)	(0.13)
Observations	5,128	5,128	5,049	5,128
R^2	0.592	0.617	0.683	0.735
Industry Fixed Effects	Y	Y	Y	Y
State Fixed Effects	N	N	N	Y

Note: The dependent variable in all regressions is log employment growth from 1950 to 2000. Observations are at the state-industry level. The first independent variable is the average number of work stoppages affecting 1,000 or more workers per year over the period 1958 to 1977, and the second is the percent of workers in the state-industry in 1950 that are college graduates. All other independent variables are measured at the state level in 1950. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

below the mean to two standard deviations above. Thus, the interpretation is that moving from near the bottom of the work-stoppage distribution to near the top is associated with 50 percent lower employment growth compared to the same industry in other states. The coefficient on the percent college graduate is positive, but statistically insignificant.

Column (2) adds in three additional state controls to the regression. The first control is the state population level in 1950, which may be relevant since less populous states had relatively lower land prices, and may have grown faster as a result. The second control is the share of employment in manufacturing. As Desmet and Rossi-Hansberg (2009) show, manufacturing industries with the highest employment levels in the 1970s had the slowest employment growth over the following decades; hence, controlling for the initial manufacturing share makes sense in this setting. The third control is a Herfindahl index of employment within each state, which measures how concentrated the state's employment was in particular industries in 1950. The decline of transportation costs since 1950 may have reduced the agglomeration advantages of one firm locating near another firm in the same industry, which may have lead to lower employment growth for states with initially more concentrated employment.

The estimates in column (2) show that indeed, higher population levels, higher manufacturing shares and higher concentrations of employment by industry are all associated with lower employment growth since 1950. For all three variables, the coefficients are statistically significant at the five-percent level or lower, and collectively these variables reduce the magnitude of the estimated coefficient on work stoppages. Still, the estimated coefficient on work stoppages remains economically large, at -0.30, and statistically significant at the one percent level.

Column (3) adds controls for three state climate characteristics: the average temperature, the within-year standard deviation of monthly temperature, and the average precipitation level. State climate differences have been put forth as determinants of cross-state employment and population dynamics by Rappaport (2007), among others, and the advent of air-conditioning clearly played an important role in the population increases in Sun Belt states like Arizona and Florida. We compute all three variables using data from the five years before and after 1950, though the variables are highly correlated across years for each state.

As one might expect, industries in states that had lower temperatures, more variable temperatures within the year or more rainfall on average had lower employment growth from 1950 to 2000, all else equal. With these climate variables in the regression, the R^2 rises to 0.683, up from 0.617 in Column (2) and 0.592 in Column (1). Thus, the temperature controls substantially increase the explanatory power of the regression. The coefficient on work stoppages remains quite similar in magnitude, however, at -0.29, and remains statistically significant at the one-percent level.

Column (4) adds a state fixed effect (but removes the other state variables) to capture any other state conditions potentially relevant for employment growth outcomes. Adding state fixed effects raises the R^2 further to 0.735, meaning that other state factors explain a substantial portion of the variance in employment growth. Still, the coefficient on work stoppages remains large in magnitude, at -0.27, and statistically significant. Thus, employment growth since 1950 is strongly related to work stoppages at the industry-state level, even after controlling for industry fixed effects and state fixed effects.[10]

5.2. Unionization Rates, 1973 to 1980

We next turn to an alternative measure of labor market conflict: the unionization rate. As described in Section 2, unionization has historically been related to labor conflict, though as Table 1 showed, unionization rates are not linked one-for-one with work stoppages. Another advantage of unionization as a proxy for conflict, relative to work stoppages, is that there may be conflict and hold up even without work stoppages.

A limitation of our unionization measure is that data at the individual level on union participation is only available in the CPS starting in 1973, and the data are only comparable up to 1980. As in the measure of work stoppages, we aggregate the data to the state-industry level, to be at a comparable level of aggregation as our other variables.

Table 6 reports the results of four regressions of log employment growth from 1950 to 2000 on unionization and the same set of other correlates as Table 5. In particular, all observations are again at the state-industry level, and all regressions include an industry fixed effect. The first column shows that unionization rates are highly negatively related to employment growth. The coefficient on unionization is -0.74, meaning that moving the unionization rate from zero to one hundred percent is associated with 74 log points lower employment growth compared to the same industry in other states. The percent college graduate is again positive but insignificant. Adding controls for population, manufacturing employment share and the employment concentration paints a similar picture, and again leaves the coefficient on unionization large, negative and statistically significant, at -0.56. Adding controls for climate variables lowers the coefficient on unionization to -0.34, and adding a state fixed effect leads to a unionization coefficient estimate of -0.30. Still, estimated coefficients on unionization are statistically significant at the one-percent level and economically large. We conclude that using unionization to proxy for work stoppages leads to a very similar picture as using work stoppages.

[10]In Appendix A, Table A.2, we explore sensitivity to various modeling assumptions and sample selection choices made in the regressions above. We find that the coefficient on work stoppages is still statistically and economically significant when using alternative definitions of major work stoppages (such as 2,000 or more, or 500 or more workers), when using any positive number of workers, or when using the fraction of all workers involved in strikes. We also find that the coefficient is negative and significant when restricting the analysis only to manufacturing industries, in which labor conflict is most prevalent, or when considering employment growth from 1950-1980, a period that corresponds more closely to the work stoppage data.

Table 6: Unionization Rates and Employment Growth

Independent Vars	(1)	(2)	(3)	(4)
	Dep. Var: Log Employment Growth 1950-2000			
Unionization Rate	-0.74***	-0.56***	-0.34***	-0.30***
	(0.076)	(0.077)	(0.075)	(0.072)
Percent College Grad, 1950	0.076	0.061	-0.022	-0.031
	(0.094)	(0.093)	(0.086)	(0.074)
Log State Population, 1950		-0.071***	-0.12***	
		(0.014)	(0.015)	
State Mfg Employent Share, 1950		-1.83***	-0.85***	
		(0.12)	(0.15)	
State Empl. Herfindahl Index, 1950		-2.41***	-1.24***	
		(0.37)	(0.36)	
State Average Temperature			0.014***	
			(0.0027)	
State Std. Dev. Temperature			-0.060***	
			(0.0070)	
State Average Precipitation			-0.014***	
			(0.0013)	
Constant	-1.49***	-0.83***	-0.39	-1.45***
	(0.096)	(0.10)	(0.25)	(0.13)
Observations	4,691	4,691	4,628	4,691
R^2	0.611	0.637	0.694	0.747
Industry Fixed Effects	Y	Y	Y	Y
State Fixed Effects	N	N	N	Y

Note: The dependent variable in all regressions is log employment growth from 1950 to 2000. Observations are at the state-industry level. The first independent variable is unionization rate over the period 1973 to 1980, and the second is the percent of workers in the state-industry in 1950 that are college graduates. All other independent variables are measured at the state level in 1950. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

5.3. Strikes from 1927 to 1934

While the results of Tables 5 and 6 are certainly consistent with our theory that labor conflict reduced employment growth, an alternative hypothesis is that the employment decline caused the conflict. In particular, one could worry that once workers realized that their firms or industries were declining, they responded by unionizing or striking.

To address this potential reverse causality story, we draw on data on labor conflict that long pre-dated the postwar employment outcomes that are the dependent variables in Tables 5 and 6. In particular, we draw on strikes data collected by the BLS in the 1920s and 1930s. The earliest data we found at the state-industry level were from 1927 to 1936, though we focus on the period 1927 to 1934, since this pre-dated the Wagner Act of 1935, which greatly increased the ability of workers nationwide to form collective bargaining arrangements. These early measures of conflict are likely related to the deep-seated distrust between workers and firms that began in this period, but is unlikely to be caused by any employment outcome starting two decades later.[11]

Table 7 presents the results of regressions of log employment growth from 1950 to 2000 on strikes from 1927 to 1934 and the same independent variable as Tables 5 and 6. Using the same set of regression controls as above, strikes from 1927 to 1934 are significantly negatively related to employment growth from 1950 to 2000. With just the percent college graduate (and the industry fixed effects) as controls, the coefficient on strikes is -0.040. Adding the state controls for initial population and economic structure lower the coefficient to -0.019, and adding state climate controls lowers the strikes estimate to -0.018. Adding state fixed effects further lowers the strikes coefficient to -0.012, though in all cases strikes are statistically significant at the one-percent level.

How does the economic significance of strikes from 1927 to 1934 relate to that of the postwar work stoppages variable? The standard deviation of strikes from 1927 to 1934 is 32, so moving from one standard deviation below the mean to one standard deviation above is associated – in regression (4) – with around 77 log points lower employment growth. This suggest an economically large effect of conflict on employment outcomes, as in Tables 5 and 6.

Overall, the results of Table 7 provide evidence against a reverse-causality story running from industry decline to conflict. Instead, the results suggest that the the causality runs from strikes to employment growth, consistent with the thesis of this paper.

[11] These data have some clear limitations. In particular, they are the two-digit industry level, which makes the mapping to the three-digit industries in the more recent data somewhat crude. Moreover, the data are only reported in states that had at least twenty five total strikes over this period. Thus, we are forced to drop states with few strikes, and this amounts to dropping around half the states and 30 percent of the total population represented by the data. These limitations make it harder to find associations between our dependent variables and our measure of strikes from 1927 and 1934. See Appendix A for more detail on these data.

Table 7: Strikes Per Year from 1927 to 1934 and Postwar Employment Growth

Independent Vars	(1)	(2)	(3)	(4)
	Dep. Var: Log Employment Growth 1950-2000			
Strikes 1927-1934	-0.040***	-0.019***	-0.018***	-0.012***
	(0.0045)	(0.0040)	(0.0040)	(0.0039)
Percent College Grad, 1950	0.087	0.10	0.033	0.024
	(0.13)	(0.12)	(0.12)	(0.11)
Log State Population, 1950		-0.093***	-0.096***	
		(0.020)	(0.023)	
State Mfg Employent Share, 1950		-2.68***	-2.05***	
		(0.14)	(0.18)	
State Empl. Herfindahl Index, 1950		3.85***	4.51***	
		(0.68)	(0.72)	
State Average Temperature			-0.0050	
			(0.0033)	
State Std. Dev. Temperature			-0.057***	
			(0.0082)	
State Average Precipitation			-0.012***	
			(0.0020)	
Constant	-1.54***	-0.70***	0.72**	-1.33***
	(0.16)	(0.18)	(0.33)	(0.19)
Observations	2,834	2,834	2,834	2,834
R^2	0.663	0.712	0.721	0.745
Industry Fixed Effects	Y	Y	Y	Y
State Fixed Effects	N	N	N	Y

Note: The dependent variable in all regressions is log employment growth from 1950 to 2000. Observations are at the state-industry level. The first independent variable is the average number of strikes from 1927 to 1934, and the second is the percent of workers in the state-industry in 1950 that are college graduates. All other independent variables are measured at the state level in 1950. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

5.4. Low Productivity Growth in Rust Belt Manufacturing Industries

In this subsection we present evidence that labor productivity growth was lower in manufacturing industries prevalent in the Rust Belt than in other U.S. manufacturing industries, at least until the 1980s, when productivity growth picked up. This is just what our model predicts. The main challenge we face is that direct measures of productivity growth by region are not available for many industries.

Table 8: 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 the mean of all industries. 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: Authors' calculations using NBER CES productivity database, U.S. census data from IPUMS, and the BLS.

Therefore, 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, this turns out to be a cutoff of at least 68 percent of industry employment located in the Rust Belt.

Table 8 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).

As the model predicts, productivity growth in Rust Belt industries picked up 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.[12]

6. Conclusion

This study builds a theory of the Rust Belt's decline since the end of World War II. We focus our theory on four main observations: (1) the secular decline in the Rust Belt's share of U.S. manufacturing employment that occurred mostly before 1980, (2) the conflicted relations between Rust Belt firms and workers, featuring high rates of work stoppages until around 1980, (3) the Rust Belt's significant wage premium from 1950 to 1980, and (3) the shift in all of these patterns after 1980, when the employment-share decline slowed, the wage premium fell and the number of strikes dropped dramatically.

In summary, our theory is that the Rust Belt decline was driven substantially by labor market conflict that manifested itself in a hold-up problem that reduced investment in the Rust Belt's main industries. This lack of investment led to movement of manufacturing employment out of the Rust Belt and into the rest of the country. After 1980, labor conflict

[12]One potential limitation of the productivity measures of Table 8 is that they do not directly measure productivity by region. However, these productivity patterns are consistent with a study that does 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.

declined, leading to higher rates of investment and productivity growth and the region's stabilization.

The substantial loss of Rust Belt employment raises the important question of why management and labor were not able to share rents more efficiently. Our model indicates that the Rust Belt's employment losses were implicitly self-inflicted, as these losses would have been much smaller had unions and firms been able to eliminate the chronic conflict and strike threats that characterized their relations. Importantly, both Rust Belt management in autos and steel, and leaders of auto and steel unions acknowledge that lack of cooperation and mistrust were central in the failure of the Rust Belt (see Strohmeyer, 1986; Hoerr, 1988; Walsh, 2010). Specifically, former UAW President Robert King stated in 2010 that: "The 20th-century UAW fell into a pattern with our employers where we saw each other as adversaries rather than partners. Mistrust became embedded in our relations...this hindered the full use of the talents of our members and promoted a litigious and time-consuming grievance culture." Future research should further analyze how labor relations and bargaining between workers and firms affect industry innovation, productivity growth, and competitiveness.

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Appendix (for Online Publication)

A. Data Appendix

A.1. Regional Cost-of-Living Differences, 1966

One potential explanation of the Rust Belt's wage premium we document in Section 2 is that the cost of living was higher in the Rust Belt than elsewhere in the United States. To address this hypothesis, we draw on the study of the U.S. Bureau of Labor Statistics (1967) that estimates costs of living across 39 U.S. metropolitan areas and 4 regional averages of urban areas not already included in one of the metropolitan areas. Their estimates are not exactly cost of living differences, since they adjust the expenditure basket in each region to take into consideration e.g. higher heating costs in colder areas. But they do attempt to capture the cost of an average budget for a family of "moderate living standards" in each city in question.

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

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

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

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

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

Belt" city. The Rust Belt is now 1.5 percentage points more expensive than the rest of the country, with a p-value of 0.22.

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

A.2. Alternative Regression Specifications

In this subsection, we explore alternative robustness specifications. Table A.2 presents the estimated coefficients on work stoppages from regressions like those in Table 5, with each row representing the results of one alternate specification. As in Table 5, the dependent variable is log employment changes between 1950 and 2000 and the observations are state-industries. The other independent variables are exactly as in Table 5.

As a frame of reference, the first row of Table A.2 reproduces the benchmark results of

Table A.2: Robustness of State-Industry Regressions

Alternative Regression	(1)	(2)	(3)	(4)
	Regression Specification			
Work Stoppages/Year, 1,000+ workers	-0.41***	-0.30***	-0.29***	-0.27***
	(0.071)	(0.063)	(0.058)	(0.056)
Work Stoppages/Year, 2,000+ workers	-0.67***	-0.50***	-0.48***	-0.44***
	(0.12)	(0.11)	(0.10)	(0.092)
Work Stoppages/Year, 500+ workers	-0.17***	-0.12***	-0.11***	-0.10***
	(0.046)	(0.038)	(0.035)	(0.036)
Work Stoppages/Year, 0+ workers	-0.019**	-0.012*	-0.011**	-0.0080*
	(0.0090)	(0.0062)	(0.0055)	(0.0048)
Percent of Workers in Stoppages	-0.13***	-0.11***	-0.090***	-0.068***
	(0.020)	(0.017)	(0.020)	(0.021)
Dep. Var: Log Employment Growth 1950-1980	-0.20***	-0.12***	-0.11***	-0.089***
	(0.041)	(0.036)	(0.032)	(0.031)
Sample Restriction: Only Manufacturing	-0.39***	-0.23***	-0.22***	-0.22***
	(0.073)	(0.059)	(0.054)	(0.056)

Note: The dependent variable in all regressions is log employment growth from 1950 to 2000 (except the second to last, which is log employment growth from 1950 to 1980. All else as in Table 5 except where indicated. Coefficients on all other independent variables are omitted for brevity. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5, where the independent variable of interest is work stoppages affecting 1,000 or more workers. The second row uses work stoppages affecting 2,000 workers or more, and keeps all else the same. Coefficients on work stoppages are larger in this case, and still everywhere statistically significant. The third and fourth rows consider lower thresholds on work stoppages, in particular 500 or more workers and 0 or more workers. These coefficients are smaller in magnitude but still statistically significant. In terms of economic magnitude, these regression still show a substantial importance of work stoppages on employment growth at the industry-state level. The reason is that, as the threshold for number of workers affected falls, the number of work stoppages affecting those fewer number of workers rises. In the case of work stoppages affecting any positive number of workers, the standard deviation rises to 3.9 from 0.9 in the benchmark. Thus, moving from two standard deviations below the mean to two standard deviations above will lead to a 13 percent decline in employment. This is comparable in magnitude to the estimate in the benchmark regression specification. We conclude that our results are not artifacts of the exact thresholds for workers affected by work stoppages.

The fifth row takes as its main independent variable the number of workers involved in work stoppages from 1958 to 1977 divided by total employment (summing over all the years) over this period. In other words, the dependent variable is the percent of workers involved in a work stoppage. Thus, instead of choosing a particular cutoff for workers involved, this alternative variable takes a more continuous measure of conflict. This independent variable also shows up with a large estimated coefficient that is statistically significant in all four cases. Thus, our results are robust to this more continuous measure of work stoppages.

The final two rows of Table A.2 stick with the benchmark independent variable of work stoppages affecting more than 1,000 workers, but change the dependent variable and sample selection. In particular, the first of these replaces log employment growth from 1950 to 2000 with log employment growth from 1950 to 1980. This time period is closer to the time period in which we observe work stoppages. Work stoppages again shows up as having a negative and significant relationship to employment growth, though with a smaller magnitude relative to the benchmark. The final row of the table is the same regression as the benchmark but restricts the sample to only manufacturing industries. The estimated coefficient on work stoppages is somewhat smaller than in the benchmark specification, but still with large economic and statistical significance. We conclude that an earlier timeframe for employment growth and restriction to just manufacturing still leave our conclusions from Section 5 intact.

B. Model Appendix

B.1. Final Good Producers' Problem and Equilibrium Prices

One can show from the first-order conditions of the final-goods producers' problem that the share of expenditures by final goods producers on manufactured goods is given by:

$$\nu \equiv \left(1 + \left(\frac{P_n}{P_m}\right)^{1-\theta}\left(\frac{1-\mu}{\mu}\right)\right)^{-1}. \tag{24}$$

To solve the final good producer's problem, we take the values of expenditure on final goods, X^r and X^s, as given, though they will be pinned down in the general equilibrium. Using (24) and X^ℓ, for $\ell \in \{r, s\}$, we can characterize the final-good producer's choice:

$$\tfrac{\nu X^\ell}{P_m} = Y_m \tag{25}$$

$$\tfrac{(1-\nu)X^\ell}{P_n} = Y_n^\ell. \tag{26}$$

One can also use the first-order conditions for the final-goods producer to derive the equilibrium price of the final good, P:

$$P = \left[\mu^\theta P_m^{1-\theta} + (1-\mu)^\theta P_n^{1-\theta}\right]^{\frac{1}{1-\theta}} \tag{27}$$

where $P_n = \frac{1}{Z_N}$ and

$$P_m = \left[(\lambda P_m^r)^{1-\sigma} + ((1-\lambda)P_m^s)^{1-\sigma}\right]^{\frac{1}{1-\sigma}} \tag{28}$$

and, for $\ell \in \{r, s\}$:

$$P_m^\ell = \left[\left(\frac{1}{z_m^\ell}\frac{\rho}{\rho-1}\right)^{1-\rho} + \left(\frac{\tau w^*}{z_m^{\ell *}}\frac{\rho}{\rho-1}\right)^{1-\rho}\right]^{\frac{1}{1-\rho}}. \tag{29}$$

B.2. Worker's Problem

Let the individual state variable of a given worker – i.e. her union status – be denoted $\upsilon \in \{0,1\}$. To solve her problem, the worker also needs to know the union rent and the union admission rate functions, $R(Z,U;\beta)$ and $F(Z,U;\beta)$, both of which depend on the endogenous aggregate state (Z,U) in addition to the exogenous state β.

Let $W_m^r(Z,U,\upsilon;\beta,\tau)$ and $\widetilde{W}(Z,U,\upsilon;\beta,\tau)$ be the values of being employed by a manufacturing firm in the Rust Belt and any other firm, respectively. The worker's value function is:

$$W(Z,U,\upsilon;\beta) = \max\{W^r_m(Z,U,\upsilon;\beta), \widetilde{W}(Z,U,\upsilon;\beta)\}. \tag{30}$$

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

$$\begin{aligned} W^r_m(Z,U,0;\beta) = F(Z,U;\beta) \times \big\{v^R\big(1 + R(Z,U;\beta,\tau) + D\big) + \delta(1-\zeta)E[W(Z',U',1;\beta')]\big\} \\ + (1 - F(Z,U;\beta)) \times \big\{v\big(1 + D\big) - \bar{u} + \delta(1-\zeta)E[W(Z',U',0;\beta')]\big\}, \end{aligned} \tag{31}$$

where v^r is the indirect utility function corresponding to U^r in equation (1), $v = \max\{v^R, v^S\}$, and the wage rate is normalized to unity.

In other words, a non-union worker who applies for admission to a labor union gets a union card with probability $F(Z,U;\beta)$, which entitles her to work in a unionized manufacturing firm in the Rust Belt. In this case she is paid the competitive wage (normalized to one) plus the union rent and the per capita dividend from the fully diversified mutual fund. The value of a successful application includes, of course, the value of membership from next period onward, which is denoted by $E[W(Z',U',1;\beta')]$. This value is discounted by $\delta(1-\zeta)$, which takes the exogenous rate of attrition ζ into account appropriately. With probability $1 - F(Z,U;\beta)$ she doesn't receive a card, in which case she gets the competitive wage plus the dividend minus the utility cost $\bar{u}$ of "queueing" unsuccessfully for union membership. The continuation value of being a non-union worker next period is $E[W(Z',U',0;\beta')]$.

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

$$W^r_m(Z,U,1;\beta) = v^r\big(1 + R(Z,U;\beta) + D\big) + \delta(1-\zeta)E[W(Z',U',1;\beta')], \tag{32}$$

which is the indirect utility from the competitive wage, the union rent, and the dividend today, plus the expected discounted value of being a union member in the future. Note that in all the parameterizations we consider, union members never quit a Rust Belt manufacturing job and always earn the union wage premium in equilibrium. They exit only via attrition, at the exogenous rate ζ. The intuition for this result is that union workers strictly prefer Rust Belt manufacturing jobs and, in addition, the exogenous attrition rate exceeds the endogenous decline of union jobs in all of our parameterizations. The measure of card-carrying members never exceeds the measure of union jobs.

Next, consider the value of employment in a non-union sector and region. In this case, a worker with union status υ has value function:

$$\widetilde{W}(Z,U,\upsilon;\beta) = v\big(1+D\big) + \delta(1-\zeta)E[W(Z',U',\upsilon;\beta')], \tag{33}$$

which is the indirect utility from today's competitive wage and dividend, plus the expected discounted value of having union status υ in the future. Non-union workers outside the Rust Belt manufacturing sector are paid the competitive wage and mutual fund dividend today plus the expected discounted utility of being a non-union worker in the future. Union members outside the Rust Belt manufacturing sector get the competitive wage today plus the expected discounted utility of being a union member in the future.

These dynamic problems admit a very simple solution to the workers' problem. As long as union rents are positive, union members strictly prefer the Rust Belt region. Non-union workers will be indifferent between the two regions only for one job finding rate, all else being equal.

B.3. Trade Balance and Foreign Wage

Our assumption of trade balance requires that expenditures on manufactures from abroad must equal foreign expenditures on manufacturing exports from the United States. Since we are focusing on a symmetric equilibrium, we can write the trade balance condition as follows:

$$\lambda p_m^{*r} y_m^{*h,r} + (1-\lambda) p_m^{*s} y_m^{*h,s} = \lambda p_m^r y_m^{h,r} + (1-\lambda) p_m^s y_m^{h,s}, \tag{34}$$

where U.S. expenditures on foreign goods are on the left hand side of the equation and foreign expenditures on U.S. manufactures are on the right hand side. Since, according to (16), $p_m^{*r,h} = p_m^{*r,f}$, $p_m^{*s,h} = p_m^{*s,f}$, $p_m^{r,h} = p_m^{r,f}$, $p_m^{s,h} = p_m^{s,f}$, we omit the h and f superscripts from the factory-gate prices for manufactured goods in equation (34).

Since households spend all their income on consumption, aggregate expenditures in the two regions are:

$$X^r = \lambda\left(\left(l_m^{r,h} + l_m^{r,f}\right)(w + D + R) + P^r C(x^r)\right) + l_n^r\,(w + D) \tag{35}$$

$$X^s = (1-\lambda)\left(\left(l_m^{s,h} + l_m^{s,f}\right)(w + D) + P^s C(x^s)\right) + l_n^s\,(w + D) \tag{36}$$

We know from equation (12) that the demand for the manufactured composite good is given by $X_m = \nu^r X^r + \nu^s X^s$, where X^r and X^s denote the final good producers' expenditures on inputs and – thanks to the zero profit condition in the final goods sector – the values of output in each region. Using this expression plus equations (35) and (36), we can close the model by solving the trade balance equation for the foreign wage rate w^*:

$$w^* = \frac{w^{1-\rho}\frac{\rho}{\rho-1}P^*(w^*)^{\sigma-1}\Big[\lambda(z_m^r)^{\rho-1}\big(P^{*r}(w^*)\big)^{\rho-\sigma} + (1-\lambda)(z_m^S)^{\rho-1}\big(P^{*s}(w^*)\big)^{\rho-\sigma}\Big]}{P_m(w^*)^{\sigma-1}X_m\Big[\lambda(z^{*r})^{\rho-1}\big(P_m^r(w^*)\big)^{\rho-\sigma} + (1-\lambda)(z^{*s})^{\rho-1}\big(P_m^s(w^*)\big)^{\rho-\sigma}\Big]}. \tag{37}$$

B.4. Cost Function

When $\mu = 1$, that is under the assumption that there are no market size effects driven by structural change, the optimality condition associated with the Bellman equation of on individual producer in sector $\ell \in \{r, s\}$ is:

$$\frac{\partial C(x,Z,z)}{\partial x}\frac{P}{z} = \delta\Big\{(1-\beta)\frac{\partial \pi_\ell(Z',z')}{\partial z'} + \frac{\partial C(x',Z',z')}{\partial x'}\frac{z''}{(z')^2}P' + \frac{\partial C(x',Z',z')}{\partial z'}P'\Big\}. \tag{38}$$

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

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

and

$$\mathcal{Z} = \left(\lambda\Big[\big(z_m^R\big)^{\rho-1} + \Big(\frac{z_m^{*R}}{\tau_C}\Big)^{\rho-1}\Big]^{\frac{1-\sigma}{1-\rho}} + (1-\lambda)\Big[\big(z_m^S\big)^{\rho-1} + \Big(\frac{z_m^{*S}}{\tau_C}\Big)^{\rho-1}\Big]^{\frac{1-\sigma}{1-\rho}}\right)^{\frac{2-\rho}{1-\sigma}} \tag{39}$$

in any symmetric equilibrium, we can show that $\frac{\partial C}{\partial x}$ is homogeneous of degree 1 with respect to all productivities. Moreover, $\frac{\partial C}{\partial z}$ is homogeneous of degree 0.

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

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

Together with the fact that the price indices are homogeneous of degree -1 (again with respect to all productivities), this implies that $\frac{\partial \pi}{\partial z}$ is also homogeneous of degree -1.

It is then straightforward to show that both sides of the optimality condition are homogeneous of degree -1. As a result, the optimal innovation rate x is scale independent and hence homogeneous of degree 0 with respect to the productivities. Since only relative productivities matter, we normalize the productivity of a Rest-of-Country producer to unity ($z_M^s = 1$) each period and express all other productivities relative to z_M^s.

The denominator of the cost function in equation (39) is one of many with the required degree of homogeneity guaranteeing that the policy x is homogeneous of degree zero with respect to all productivities. However, this particular functional form for the denominator has an additional property that we believe is useful and noteworthy in its own right. In the special case of the economy with no union hold-up ($\beta = 0$), free trade ($\tau = 1$), and no comparative advantage $\left(\frac{Z_r^*}{Z_r} = \frac{Z_s^*}{Z_s} = \mu\right)$, the policy x does *not* depend on the aggregate endogenous state Z and an individual firm will grow at a constant rate regardless of its own productivity z. Put differently, the economy is on a balanced growth path.

Since the price indices are equalized across countries whenever $\tau = 1$ and countries are only differentiated by the absolute advantage (parameterized by μ), the trade balance condition (34) can be simplified to:

$$w^* = \mu^{\frac{\rho-1}{\rho}} \tag{40}$$

After substituting the expression for the foreign wage into the optimality condition (38) and exploiting the fact that $P = P^*$ and $P_\ell = P_\ell^*$ for $\ell \in \{r, s\}$, the endogenous state variables (i.e. the idiosyncratic and aggregate productivities) drop out and the optimal innovation rate is only a function of the parameters and the extent of foreign's *absolute* advantage, denoted by μ.