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Firm Dynamics and Residual Inequality in Open Economies

By

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Abstract

Wage inequality between similar workers has been on the rise in many rich countries. Recent empirical research suggests that heterogeneity in firm characteristics is crucial to understand wage dispersion. Lower trade costs as well as labor and product market reforms are considered critical drivers of inequality dynamics. We ask how these factors affect wage dispersion and how much of their effect on inequality is attributable to changes in wage dispersion *between* and *within* firms. To tackle these questions, we incorporate directed job search into a dynamic model of international trade where wage inequality results from the interplay of convex adjustment costs with firms' different hiring needs along their life cycles. Fitting the model to German linked employer-employee data for the years 1996-2009, we find that firm heterogeneity explains about half of the surge in inequality. The most important mechanism is tougher product market competition driven by domestic product market deregulation and, indirectly, by international trade.

JEL-Codes: F12, F16, E24.

Keywords: Wage Inequality, International Trade, Directed Search, Firm Dynamics, Product and Labor Market Regulation.

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1 Introduction

Economic inequality has been on the rise in many industrialized countries. According to a recent OECD study, since the mid-1980s, inequality increased in 17 out of 22 OECD member states for which data are available (OECD, 2011). This trend has been particularly pronounced in post unification Western Germany where, measured by the standard deviation of log gross wages, inequality has increased by about 70% from 1975 to 2009. Most of the adjustment has taken place since the mid 1990s, after formerly communist Middle and Eastern European countries signed free trade agreements with the EU, the so called Europe Agreements, leading to a remarkable increase in Germany's international trade. In the early 2000s, the country also undertook substantial reforms aimed at deregulating its product and labor markets: the Hartz reforms produced a radical restructuring of the labor market, and the European Union's single market program led to ambitious reforms of the product market. The conjunction of these changes makes it difficult to assess their relative contributions to the observed inequality dynamics.

In Germany, only a small fraction of wage inequality is attributable to observed worker characteristics, while plant characteristics are much more important, either directly or through their interactions with unobserved worker effects (Card et al., 2013). Using a rich linked employer-employee data set provided by the Institute for Labor Market Research (the so called LIAB data set) we find that about half of increase in residual inequality between 1996 and 2009 can be attributed to the between-firm component, the dispersion of average pay across firms. Traditionally, the literature has stressed changes in the relative returns to education and/or capital. However, these explanations, epitomized by the Stolper-Samuelson theorem, cannot account for the increase in wage dispersion *within* narrowly defined skill classes, occupations, or industries. Moreover, assuming perfectly competitive markets, the literature often has no means to analyze many labor and product market reforms.

In order to address these shortcomings, we propose a theoretical model of trade with frictional labor markets that generates wage dispersion among similar workers between and within firms. Then, we calibrate the model to German linked employer-employee data and provide a quantitative assessment of the role of international trade, domestic product market reform, and institutional change in explaining inequality dynamics. The model introduces directed labor market search and convex adjustment costs into a general equilibrium model where firms enjoy different levels of productivity and commit to wage contracts. The model provides a fairly tractable theory of wage dispersion amongst *homogeneous* workers based on differences in firm

sizes and growth rates. Due to convex adjustment costs, firms find it optimal to add employment gradually. More productive firms have higher optimal sizes and, thus, grow faster than less productive firms. These different adjustment needs translate into different wage policies: firms undertaking larger adjustments find it optimal to offer higher wages in order to attract more applicants, which enables them to reduce their total recruitment costs. Since revenue functions are concave, adjustment is fastest in earlier stages. This generates wage dispersion within firms because workers hired at earlier stages of a firm's life cycle are offered contracts with higher present values.

We show that hiring schedules are governed by non-linear second order ordinary differential equations. In general, they cannot be solved analytically and the equilibrium has to be characterized numerically. For this reason, we explain the model dynamics in a simplified one-period setup, where the standard Melitz (2003) model emerges in the limit case without search frictions. The model generates a positive correlation between wages and firm productivity. It predicts that inequality is higher in open economies, but that it is hump-shaped in the degree of openness. If adjustment costs are strongly convex, growing firms resort to very aggressive hiring policies that guarantee high job filling probabilities but lead to low job finding rates. Consequently, unemployment may increase as trade costs fall.

Firm dynamics are important for our quantitative exercise. With continuous time, firms spread their adjustment needs and this tends to relax the effect of trade on inequality. Compressing adjustment into one period would exaggerate the trade-inequality nexus. Moreover, the dynamic model is consistent with a new stylized fact according to which firms grow by filling their vacancies faster. Davis et al. (2013) use US establishment-level data and find that vacancy filling rates rise steeply with firm employment growth rates. We also show that these predictions are consistent with the relationship between plant size, growth, and wages found in the LIAB data. Our framework generates both within and between firm wage dispersion as in the data. The reason is that young firms have steeper growth profiles, hence workers hired by firms in their early stages are offered higher wages compared to those offered to workers hired in more mature stages of the firm life cycle. Finally, in our model, there is always a measure of young but productive firms that would at some point in their lifetime become exporters but have not yet reached the required critical size.

We calibrate the dynamic model to German data, using firm and worker information from the LIAB data set. We fit the parameters to salient cross-sectional and aggregate statistics for the year 1996. The model generates a good fit of several key statistics, such as average firm size, the share of exporting firms, the tenure profile of wages, the export wage premium and the

between-firm component of residual wage dispersion. Moreover, the link between firm growth and wages reproduces about 40% of total residual wage inequality observed in the data. Hence the model generates a quite large wage dispersion, considering that the firm growth-wage link is the only engine of inequality and that frictional labor market models notoriously struggled to generate large wage inequality (Hornstein et al. 2010).

In our comparative statics exercises we evaluate the effects of recent trade, product and labor market reforms in Germany. We adjust trade costs such that the model replicates the change of German trade shares observed between 1996 and 2009. We also analyze the effect of lower unemployment benefits and of higher job search efficiency associated with the Hartz reforms. Moreover, in our data, the median markup of firm revenues over variable costs fell from 30% to 24% between 1996 and 2009. We relate this increase in product market competition to a higher elasticity of demand. We find that the observed reduction in markups is associated to an increase in overall inequality by a factor of about 1.5 (while the data features an increase by 1.8), and that it explains almost the entire dynamics of the relative importance of the between-firm component of inequality. In contrast, lower trade costs (at constant markups) and the Hartz reforms have only minor effects on wage inequality while they matter for the rate of unemployment. Our key result linking markups and wage dispersion can be explained as follows: an increase in demand elasticity raises the size premium for more productive firms, hence for a given distribution of productivity firm size distribution becomes more dispersed. Since the process of firm growth in our economy links firm size to wages, increases in demand elasticity leads to more dispersion in firm size and ultimately to higher wage inequality.

Related literature. A number of recent papers have investigated how changes in the distribution of firm revenues brought about by trade liberalization map into changes in the distribution of individual wages of observationally identical workers.¹ We go beyond the literature by broadening the focus to a wider range of possible drivers of inequality.

Our frictional labor market with directed search and large firms builds on work by Kaas and Kircher (2015).² In contrast to this seminal paper, we allow for general equilibrium feedbacks through firms' revenues, introduce international trade along the lines of Melitz (2003), and focus on wage inequality. Coşar et al. (2016) have also introduced search and convex adjustment

¹Another literature focuses on the role of trade in affecting the skill premium in representative firms economies (e.g., Acemoglu, 2003; and Epifani and Gancia, 2008), and in models of firm heterogeneity (e.g., Yeaple, 2005; Harrigan and Reshef, 2012)

²Kaas and Kircher (2015) extend Moen's (1997) seminal model to an environment where firms employ multiple workers. In related work, Garibaldi and Moen (2010) characterize a directed search model with convex vacancy costs and on-the-job search.

costs into the Melitz model. However, their assumptions of random search and continuous renegotiation of wages counterfactually imply that firms grow by posting more vacancies and not by recruiting faster, and that there is no within-firm wage dispersion. Smooth firm growth and export dynamics is also generated in Fajgelbaum (2013), where search frictions in job-to-job transitions slow down firm growth and entry into export markets with implications for aggregate income and welfare. However, his paper does not study inequality.

Helpman et al. (2010) use a random search model with two-sided heterogeneity and assortative matching.³ Workers have different abilities that can be detected through a costly screening process. As more productive firms can put ability to better use, they invest more in screening, hire more able workers, and pay higher wages. This mechanism generates a non-degenerate wage distribution. It is strengthened when trade costs fall. The key difference between the two models is that we present a theory of wage dispersion based on firm characteristics only, whereas wage inequality in Helpman et al. (2010) is produced by assortative matching between unobserved workers' abilities and firms. Recently, Card et al. (2013) have used German social security data to show that assortative matching and firm characteristics account for up to 16% and up to 21% of the overall dispersion of wages, respectively. Hence, our papers offer two complementary theories of wage dispersion; each accounting for a source of inequality that proves to be substantial in the data.

A number of papers offer quantitative perspectives. Helpman et al. (2012) structurally estimate the Helpman et al. (2010) model on Brazilian data; Egger et al. (2013) and Hauptmann and Schmerer (2013) apply fair wage models to data from France and Balkan countries and to Germany, respectively; Amiti and Davis (2011) provide reduced form evidence for their model from Indonesian data. All these papers find that trade has a non-negligible impact on the distribution of wages. By contrast, Cosar et al. (2016) take their model to the Colombian data and do not find quantitatively important effects of trade on inequality. Similarly, our quantitative analysis suggests that trade was not decisive in shaping German wage dispersion in recent decades. Interestingly, a common feature distinguishing Cosar et al. (2016) and our paper from the rest of the literature, is the use of a dynamic model with convex adjustment costs. This weakens the response of wages to trade liberalization as firms optimally spread their adjustments over time. A recent paper by Bellon (2016) also indicates that the effect of trade

³The papers by Helpman and Itskhoki (2010) and Felbermayr and Prat (2011) feature random search, bargaining, and linear adjustment costs. This implies constant wages amongst homogeneous workers. Egger and Kreckemeier (2009) and Amiti and Davis (2012) assume that more productive firms must pay 'fair' wages linked to productivity or operating profits; else, workers do not exert effort. Davis and Harrigan (2012) present a trade model in which firms pay efficiency wages to induce worker effort. Firms with higher labor productivity pay higher wages if they possess an inferior monitoring technology.

crucially depends on the time horizon. Calibrating a model of directed search with large firms and heterogeneous workers, Bellon (2016) finds that trade liberalization has little impact in the long-run although inequality overshoots on the path to the new steady state.

A concurrent line of empirical research focuses on how within-firm inequality shapes the dynamics of wage dispersion. Mueller et al. (2015) show that pay differentials between high and low skilled jobs in the UK correlate with firm size. Barth et al. (2014) find that much of the increase in inequality in the US in the period 1992-2007 comes from increased dispersion of earnings among establishments. Bloom et al. (2015) use a rich US employer-employee data set to show that within-firm inequality is fairly stable and that most of the increase in top-incomes is due to the average pay of the firm rather than the within firm pay structure. We provide evidence that a similar dynamics is at work in Germany in recent decades. Given this evidence, our paper appears to be the first appear to provide a quantitative perspective on the determinants of within and between firm inequality in general equilibrium.

So far, the recent evolution of wage dispersion in Germany has been analyzed using reduced-form econometrics only; see Dustman et al. (2008) and Card et al. (2013). Dauth et al. (2014) present reduced form empirical evidence on the role of trade with Eastern Europe and China for employment in Germany. Two interesting papers by Launov and Waelde (2013) and Krebs and Scheffel (2013) provide a quantitative analysis of the Hartz reforms. However, they focus on unemployment and not on wage dispersion, and they do not contrast institutional reform to product market liberalization. We appear to be the first to develop a structural analysis of wage dispersion in Germany.

Outline of the paper. Section 2 provides a set of stylized facts on the evolution of inequality, trade, and institutions in Germany in recent decades. Section 3 lays out the baseline dynamic model with firm adjustment and forward-looking worker behavior. Section 4 sketches a simple one-period model and presents analytical results on the effect of trade liberalization. Section 5 uses the evidence documented in section 2 to calibrate the dynamic model and explores its properties numerically. The quantitative analysis assesses the role of trade and institutional reforms in shaping the recent dynamics of German wage inequality. Section 6 concludes. Technical details and proofs are relegated to an Appendix.

2 Germany After the Fall of the Iron Curtain

2.1 Rising gross wage inequality

From 1985 to today, gross wages inequality has sharply increased in Germany, with a substantial acceleration around the year 1993. We use administrative worker-level data based on social security records to document these facts. More precisely, we work with a 2% random sample of the universe of employed persons under social security (i.e., excluding the self-insured). These data are provided by the Institute for Labor Market Research, the official research body of the Federal Employment Agency.⁴

Following common practice, we focus on male full-time workers aged 20 to 60 with work places in Western Germany for the years 1975 to 2009. Figure 1 plots the variance of log daily wages. It shows that this measure of inequality has doubled from 0.14 in 1985 to 0.28 in 2009. Strikingly, more than 90% of this increase has taken place since 1993.⁵

Observable worker characteristics are only of limited help in explaining the rise of wage inequality. To show this, we run yearly Mincerian wage regressions of the form $\ln w_{it} = \beta \mathbf{X}_{it} + \omega_{it}$ where the vector \mathbf{X}_{it} contains dummy variables capturing four educational categories as well as a cubic experience term. We find that, from 1985 to 2009, the variance of log residual wages ω_{it} has increased by 0.09 points from about 0.09 to 0.18 (see Figure 1). It exhibits a very similar trend as raw inequality.⁶ Also, there is evidence for a break in the series around the year 1993. Hence, the evidence suggests that worker observables such as education and experience explain only about one third of the increase in wage inequality since 1985. So, traditional theories based on observational differences between groups of workers, such as the Stolper-Samuelson theorem or mechanisms based on skill-biased technical change, explain only a fraction of the increase in inequality in Germany.

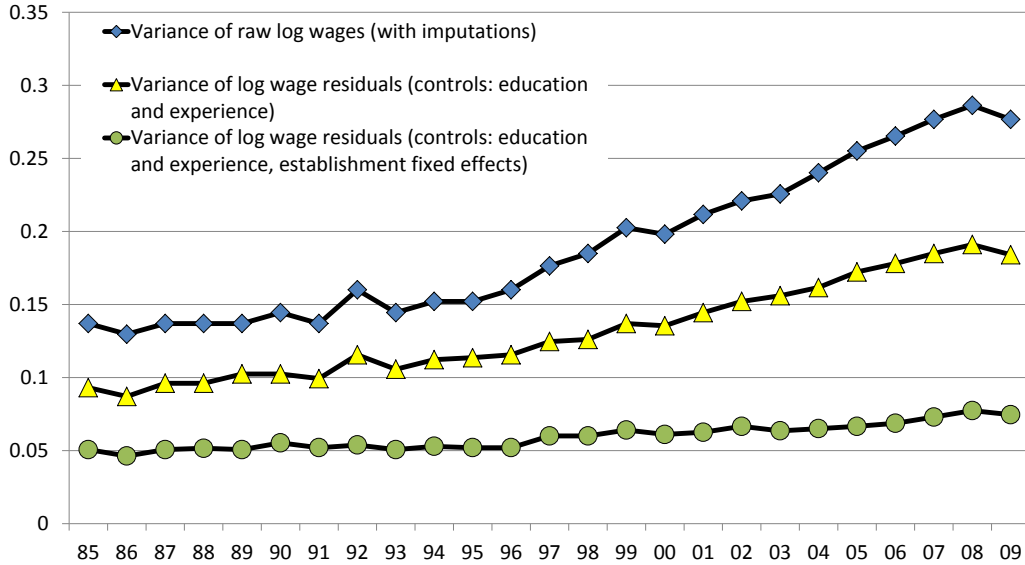
By contrast, adding firm fixed effects to the Mincer regression leads to a different picture: the variance of the residuals from such a regression is almost flat over time, moving from 0.05

⁴German social security data covers the whole workforce subject to unemployment insurance. The data is deemed of very high quality. Wage income is censored at the annual Social Security earnings maximum. This affects at most the 14% highest incomes. We use well-established imputation algorithms to deal with this problem; see Dustmann et al. (2009) for a discussion. The 2% sample is known as the SIAB data base; a matched employer-employee data set is also available (LIAB data). See Appendix B.1 for details.

⁵A similar finding, based on variants of the same data set, is reported by Dustmann et al. (2009) and Card et al. (2013). These authors document that the overall trend and its break in the mid 90s is robust to using alternative inequality measures such as interquartile comparisons of the wage distribution. Fuchs-Schuendeln et al. (2010) confirm the findings using census and survey data.

⁶Similar evidence is found by Violante et al. (2011) for the US, by Jappelli and Pistaferri (2011) for Italy, and by Blundell and Etheridge (2011) for the UK. Evidence for emerging countries is provided by Helpman et al. (2012) for Brazil; or by Xing and Li (2011) for China.

Figure 1: The variance of raw and residual wages over time in Germany



Notes. Variances of log raw daily wages for male, full-time workers in Western Germany using the 2% sample of German social security data (SIAB). Residual wages from yearly Mincer regression controlling for education and experience, including dummies for region and industry.

in 1985 to 0.06 in 1996 to 0.07 in 2009.⁷ This analysis suggests that establishment fixed effects (together with the standard Mincer controls) explain more than 80% of the total increase in inequality in Germany.⁸

While this last finding suggests an important role for plant-specific effects in explaining total wage inequality in Germany, it is based on a regression design that does not control for unobserved worker abilities and which may therefore be spurious. Card et al. (2013) go beyond this analysis by imposing a log-linear structure such as in Abowd et al. (1999) and assuming that the movement of workers across firms is conditionally exogeneous. They decompose the overall variance of observed wages into its components: the variance of an index of worker observables, the variance of the worker effect, the variance of the plant effect, and the covariances between pairs of these objects. Card et al. (2013) employ a regression design that identifies worker and plant effects over 6 year intervals. They work with the same data that underlies our Figure 1.⁹

⁷To be perfectly precise: our data identify the establishment (the plant) at which a worker is employed, not a firm. In the sequel, we treat plants and firms as synonymous.

⁸Woodcock (2008) documents the important role of firm effects for the US while Torres et al. (2013) ascribe about 30% of the overall wage variance in Portugal to firm effects.

⁹Card et al. (2013) use the full population rather than the 2% sample, which enables them to identify worker effects. Their regression model is given by $\ln w_{it} = \alpha_i + \psi_{j(i,t)} + \beta X_{it} + r_{it}$, where α_i is a worker effect, $\psi_{j(i,t)}$ is the establishment component, X_{it} is an index of time-varying worker observables and r_{it} is a random disturbance.

Table 1: Decomposition of log wage variance

	1985-1991		1990-1996		1996-2002		2002-2009		Change	
	Contrib.	%	Contrib.	%	Contrib.	%	Contrib.	%	Abs.	%
Person effects	0.084	61	0.093	63	0.107	58	0.127	51	0.043	39
Plant effects	0.025	19	0.029	20	0.038	21	0.053	21	0.028	25
Covariate index	0.015	11	0.007	5	0.008	4	0.007	3	-0.008	-7
Cov(person, plant)	0.003	2	0.006	4	0.018	10	0.041	16	0.038	34
Sum	0.137		0.147		0.184		0.249		0.112	

Notes. Table based on variance decomposition in Card et al. (2013) using log daily wage data for West German, male, full-time workers, aged 20-60, as reported in German social security data (the same data as used in Figure 1); covariates include year dummies, a quadratic and cubic term in age, all fully interacted with educational attainment.

Table 1 shows that, in any cross-section, the variance of the person effects provides the largest contribution to the variance of individual wages, ranging between 63 and 51%. The second most important contribution to the overall variance comes from plant effects, with a variance of 0.029 in the 1990-96 period and of 0.053 in the 2002-09 period.¹⁰ Our work tries to rationalize the existence of such plant effects and how they are affected by trade liberalization or institutional reform. Notice, however, that the specification applied by Card et al. (2013) implies that worker and firm effects are additively separable; this rules out match effects arising from log supermodularity between unobserved worker and firm characteristics. So, the variance attributed to firm effects in Table 1 may be inflated by match-effects. As a consequence, we use the Card et al. (2013) results as a reference point against which to evaluate the decomposition predicted by our model, but we do not directly target any of the moments displayed in Table 1.

Table 2: Decomposition of log residual wage variance into a within and a between plant component

	1996		2009		Change	
	Contrib.	%	Contrib.	%	Contrib.	%
Within	0.06	50	0.08	43	0.02	35
Between	0.06	50	0.10	57	0.04	65
Sum	0.12	100	0.18	100	0.06	100

Notes. Decomposition using log daily wage data for West German, male, full-time workers, aged 20-60, as reported in German social security data (LIAB data).

¹⁰The variance components missing in Table 1 (the variance of the residual, the covariances between plant or person effects with the covariate index) make up less than 8% and do not show any significant trend.

Finally, we decompose the variance of log residual wages into a within-plant and a between-plant component.¹¹ We do so using the LIAB data set, and report the years 1996 and 2009. We find that, in 1996, both components were of similar importance for total wage inequality; in 2009, the relative weight of the within component has decreased to about 43%. Thus, about two thirds of the total increase in inequality is due to the between component. This is in line with the recent findings by Bloom et al. (2015) for the US.

The evidence suggests an important role for firm effects. It also shows that a non-trivial share of the increase in wage inequality is driven by the between-firm component. While Helpman et al. (2010) analyze the link between trade and the extent of assortative matching, our model focuses on the the role of firm effects for both between and within firm components of wage inequality.

2.2 Increasing competition and institutional reform

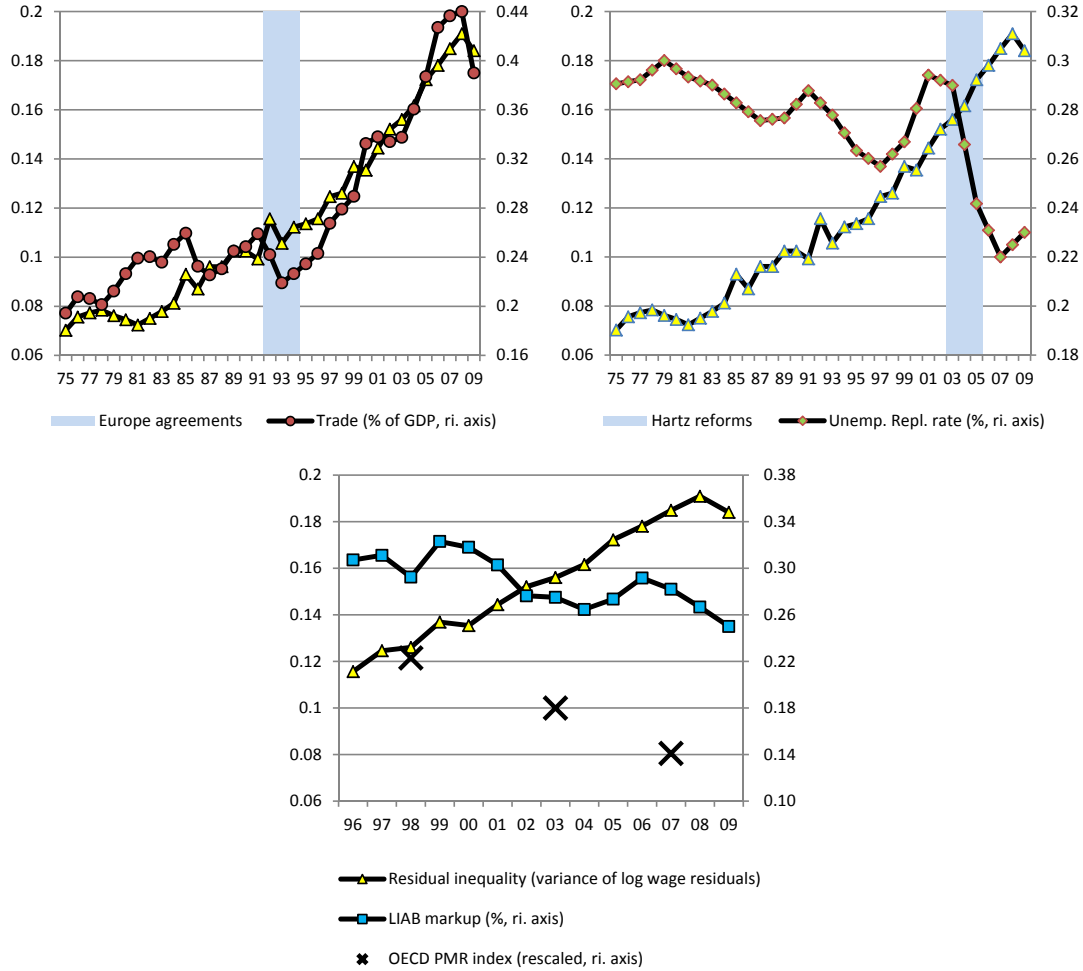
There is an open debate as to the relative roles of labor market reform, technological change, product market deregulation, and international trade in explaining the facts described above. In their empirical work, Autor et al. (2013, 2014) have forcefully argued that exposure to competition from China has led to higher wage inequality in the US; Dauth et al. (2014) use similar econometric techniques to show that increased trade with Eastern Europe and China has also boosted earnings dispersion in Germany. Others such as Dustmann et al. (2014) stress the role of institutional changes, in particular labor market reforms. These papers cannot always fully control for other drivers of inequality. Our strategy is to employ a structural equilibrium model where we have full control over counterfactuals.

The upper-left diagram in Figure 2 shows that trade openness has moved very much in tandem with inequality, so that increasing trade integration appears as a potential explanatory variable. The figure plots the ratio of total trade over GDP on the right-side axis. While that measure did not exhibit any positive trend from 1985 to 1993, it rose from 22% to 39% over the 1993-2009 period.

After the end of communism in Middle and Eastern Europe, German firms gained access to markets in its neighborhood with more than 100 million potential consumers. Already in 1991, the European Community had signed a free trade and association agreement with Poland, agreements with other Eastern European countries followed. This led to a massive expansion of

¹¹We use the formula $\sigma^2 = \sum_z p_z \sigma_z^2 + \sum_z p_z (\bar{w}_z - \bar{w})^2$, where z indexes a firm, p_z is the employment share of firm z , \bar{w}_z is the mean wage within a firm z , and σ_z is the standard deviation of wages within a firm z . Elements without firm indices refer to the full sample.

Figure 2: Residual inequality, trade, and labor market reform



Notes. Inequality data as in Figure 2. Trade refers to exports plus imports over two times GDP. Data from German Federal Statistical Office (Destatis). Gross unemployment replacement rates from OECD (www.oecd.org/els/social/workincentives). Markups computed based on LIAB data. Product market regulation (PMR) index from Koske et al. (2015).

trade which is clearly evidenced by the aggregate trade share plotted in Figure 2. A second boost to German trade openness occurred following China’s accession to the World Trade Organization (WTO) in late 2001. The strong increase in openness is confirmed with alternative openness measures. Table 3 shows a measure of the German value added content in foreign demand over total German value added (GDP). That measure has increased by less than the overall trade share (due to the increased importance of foreign inputs in German exports). Nevertheless, the approximately 30% increase in openness registered between 1995 and 2008 still represents a

substantial change.¹² The table also shows that export growth was driven by both the extensive and the intensive margins: the share of manufacturing firms that engage in exporting has risen from 18 to 30%, while the share of exports in the total sales of these firms increased from 20 to 29%. Interestingly, the rise in inequality has been accompanied by a fall in the unemployment rate from close to 10% to 7.8% in 2009.

Table 3: Aggregate statistics for Germany

	1996	2009	Source
Openness			
Agg. export openness (VA based) ¹⁾	16.69%	27.75%	OECD-WTO TiVA data base
Share of plants with exports ²⁾	18.00%	30.00%	LIAB data base
Share of exports in exporter sales ²⁾	20.00%	29.00%	LIAB database
Institutions			
Gross replacement rate ³⁾	26.00%	23.00%	OECD, tax benefits models
Product market regulation (index) ⁴⁾	0.22	0.14	OECD, Koske et al. (2015)
Markup ²⁾	30%	24%	LIAB data base
Labor market outcomes			
Variance of raw log wages	0.16	0.28	SIAB data base
Variance of residual log wages	0.12	0.18	SIAB data base
Unemployment rate	9.90%	7.80%	Destatis
Firm-level average employment levels²⁾			
non-exporter plants	12.74	13.89	LIAB data base
exporter plants	96.61	89.56	LIAB data base
all plants	27.56	35.12	LIAB data base

Notes. ¹⁾ Domestic value added embodied in foreign final demand as % of total value added (GDP); data refer to 1995 and 2008. ²⁾ based on information from LIAB data base, manufacturing sector. ³⁾ first year refers to 1995. ⁴⁾ years refer to 1998 and 2008.

Besides ever deeper global integration, Germany enacted an ambitious overhaul of its labor market institutions. The so called Hartz reforms aimed at accelerating labor market flows and reducing unemployment duration. The first two of these reforms, Hartz I and II, active from January 2003, implemented new training programs, new forms of employment for elderly workers and introduced the so called ‘mini-jobs’, mainly consisting in tax deductions for low-paid or part-time workers. Hartz III, operative from January 2004, consisted in a substantial reform of the federal employment agency which led to the creation of ‘job centers’ aimed at improving assistance and providing efficient advice to job seekers.¹³ While the first three reforms focused on promoting new forms of employment and improving the job search process, Hartz IV, effective from January 2005 modified the rules for eligibility of unemployment assistance, leading to a

¹²These are the years for which the OECD provides the data.

¹³See Jacobi and Kluve (2007) for a detailed description of the Hartz reforms.

reduction in average levels and duration of unemployment benefits.

In order to evaluate the effects of the first three reforms, Fahr and Sunde (2009) and Hertweck and Sigrist (2012) provide an estimation of the matching function and of its changes after the reforms. Their main result shows that the reforms, especially Hartz III, produced a substantial improvement of the efficiency of the matching process in Germany. Fahr and Sunde (2009) find that the flows from unemployment to employment accelerated by 5-10%, corresponding to a reduction in the average unemployment duration of the same order of magnitude. In the upper-right diagram in Figure 2, we report OECD estimates of gross unemployment replacement rates for Germany, which document a decline from a level of 29% in 2001 to 23% in 2009.¹⁴ However, the generosity of unemployment benefits has been on a downward trend even before.¹⁵

Finally, like many other OECD countries, Germany has substantially deregulated its product market. According to information from the OECD's product market regulation (PMR) data base, from 1998 to 2008 the index of PMR intensity has fallen from 0.22 to 0.14;¹⁶ about three quarters of this decline happened from 1998 to 2003 (Koske et al., 2015). The lower diagram in Figure 2 provides an illustration. This index is based on several measures of product market regulations broadly grouped in state control indicators (e.g. scope of public enterprises, price controls), barriers to entrepreneurship (e.g. administrative and legal burdens, barriers to entry), and barriers to trade (e.g. barriers to FDI, discriminatory procedures against foreign firms). Decomposing the sources of regulatory reforms for Germany shows that the liberalization push came mostly from the reduction of state controls and of barriers to entrepreneurship.¹⁷ The deregulation of the product markets and increased foreign competition may have lowered profit margins of German firms. The lower diagram in Figure 2 plots proxies for markups derived from the LIAB data set. Operating profits are calculated as revenues minus total costs, where total costs are made up of the wage bill plus material inputs. Markups are defined as the share of operating profits in revenues. Quite strikingly, some volatility notwithstanding, markups have trended downwards from about 31% in 1996 to about 25% in 2009.

¹⁴See the data on www.oecd.org/els/social/workincentives.

¹⁵Another important change in labor market institutions in those years is the reduction in collective bargaining coverage which followed German reunification. The German LIAB data show that about 80% of all firms were covered by industry agreements in 1996; this share declined to about 60% in 2009, with most of the decline occurring prior to 2005. We do not study this institutional change here; for an empirical analysis of the links between the fall in collective bargaining and wage inequality in Germany see Dustmann et al. (2009) and Card et al. (2013).

¹⁶To ease the presentation, the original OECD index was rescaled using the factor 0.1.

¹⁷See Wolf et al. (2015) Table 2. Importantly, that measure is much wider in scope than any index of trade openness.

3 Model

We propose a continuous time framework that brings together the Melitz (2003) trade model with the directed search approach of Kaas and Kircher (2015). Trade between two symmetric countries is subject to variable and fixed costs, while the labor market is characterized by search-and-matching frictions and convex adjustment costs.¹⁸ Workers are homogenous but firms are heterogenous with respect to their productivity.

3.1 Model setup

Final output producers. Consumer preferences are linear over a single final output good Y that is produced, under perfect competition, according to an aggregate CES production function

$$Y = M^{-\frac{1}{\sigma-1}} \left[\int_{\omega \in \Omega} y(\omega)^{\frac{\sigma-1}{\sigma}} d\omega \right]^{\frac{\sigma}{\sigma-1}}, \quad \sigma > 1, \quad (1)$$

where the measure of the set Ω is the mass M of available varieties of *intermediate* inputs, ω denotes such an input, $y(\omega)$ is the quantity of the input used, and σ is the elasticity of substitution across varieties. The term $M^{-1/(\sigma-1)}$ neutralizes the scale effect due to *love of variety* otherwise present in CES aggregator functions.¹⁹ The price index dual to (1) is given by

$$P \triangleq \left[\frac{1}{M} \int_{\omega \in \Omega} p(\omega)^{1-\sigma} d\omega \right]^{\frac{1}{1-\sigma}}, \quad (2)$$

and is used as the numeraire, i.e., $P = 1$. Then aggregate income is simply equal to Y . With these assumptions, demand for an intermediate good ω is given by the isoelastic inverse demand function

$$y(\omega) = \frac{Y}{M} p(\omega)^{-\sigma}. \quad (3)$$

Intermediate input producers. Producers of intermediate goods operate under monopolistic competition. Payment of an entry fee of $f_E/(r + \delta)$ allow firms to draw their *time-invariant* productivity levels $z(\omega)$ from a sampling distribution with c.d.f. $G(z)$. Productivity remains constant over a firm's lifetime, but employment $\ell_a(\omega)$ is a function of firm age a . Output is

¹⁸We opt for a symmetric framework, mostly for the sake of tractability and to avoid simplifying but problematic assumptions (such as the introduction of a linear outside sector). Trade costs have fallen symmetrically; hence, our setup comes with little loss of generality.

¹⁹This avoids a counterfactual negative correlation between the unemployment rate in autarky and the size of the country (labor supply). With trade and symmetric countries, this counterfactual implication is maintained on the world level. See Felbermayr, Prat, and Schmerer (2011) for a discussion of the case of positive gains from variety.

given by a linear production function

$$y(\ell_a; \omega) = z(\omega) \ell_a(\omega). \quad (4)$$

Due to monopolistic competition, each firm produces a unique variety; the dependence of z and optimal ℓ on ω is understood and suppressed in the present section.

Firms need to pay a flow fixed cost f in order to operate domestically and another flow fixed cost $f_X > f$ if they are present on the export market. Each unit of production shipped abroad is subject to an iceberg-type variable trade cost $\tau \geq 1$. As will be shown later, due to the presence of fixed market access costs in equilibrium only firms with sufficiently high productivity levels $z \geq z_D^*$ find it profitable to operate, and only the most productive firms featuring $z \geq z_X^* > z_D^*$ will also decide to export.

Revenues from exporting are $p_X y_X / \tau$ and producers face the same demand (3) for domestic and foreign sales. Thus prices and quantities in the domestic and foreign markets satisfy: $p_X(z) = \tau p_D(z)$ and $y_X(z) = \tau^{1-\sigma} y_D(z)$. Total revenues are therefore given by

$$R(\ell_a, \mathbb{I}_a; z) = \left[\frac{Y}{M} (1 + \mathbb{I}_a \tau^{1-\sigma}) \right]^{\frac{1}{\sigma}} (z \ell_a)^{\frac{\sigma-1}{\sigma}}, \quad (5)$$

where \mathbb{I}_a is an indicator function that takes value 1 when the firm serves the foreign market and 0 otherwise.

Directed job search. Labor is the only factor of production. Transactions in the labor market are segmented over a continuum of submarkets, each indexed by its ratio of open vacancies to job seekers $\theta = V(\theta) / S(\theta)$.²⁰ The matching function in each submarket features constant returns to scale. Thus, if we let $q(\theta)$ denote the vacancy filling rate (with $\partial q(\theta) / \partial \theta < 0$), $\theta q(\theta)$ is the rate of finding a job (with $\partial [q(\theta) \theta] / \partial \theta > 0$). We use $\eta \triangleq -q'(\theta) \theta / q(\theta)$ to denote the *constant* elasticity of the filling rate with respect to θ .

Firms are destroyed at the *time-invariant* Poisson rate δ . Workers and firms separate at the natural attrition rate χ . Both δ and χ are treated as exogenous. New firms are continuously created. They differ with respect to their innate productivity levels but start their lives equally small. They grow smoothly over time due to the presence of convex adjustment costs, with growth rates depending on productivity. This leads to a cross-section of firms whose employment levels

²⁰ $V(\theta)$ and $S(\theta)$ denote the number of open vacancies and job seekers in the submarket with tightness θ . When we refer to ‘labor market tightness’, we take the perspective of searching workers. A lower value of θ , thus, reflects a tighter labor market.

depend on both age and productivity.

We assume that search is directed and that firms have the ability to commit. They post contracts which stipulate wage rates w for any point in time at which the firm operates. Since workers are risk neutral, they do not have preferences over the timing of payments as long as they yield the same discounted sum. Thus we simplify matters by considering that workers are offered a constant income stream. This choice of wage profile is also without loss of generality from the firm's standpoint: it does not affect its optimization problem because promised wages are sunk and, as such, do not affect future decisions. By committing to a wage, firms decide in which submarket θ they want to recruit and how many vacancies they want to create. Workers have information about each submarket prior to their search and use it to select the submarket in which they apply. Hence conditions across submarkets must be such that workers are indifferent.

It is convenient to derive first the reservation wage as well as the indifference condition relating wages across submarkets. Workers' asset values satisfy the following conditions

$$\begin{aligned} rE(w) &= w + (\delta + \chi) [U - E(w)], \\ rU &= b + \theta q(\theta) [E(w) - U], \end{aligned}$$

where the interest rate is denoted by r and unemployment benefits (the value of leisure) by b . The flow value of employment is $rE(w)$. By definition, the reservation wage w_r is such that $rU = w_r$.

Substituting $E(w)$ out of the above system and using $w_r = rU$, we obtain

$$w_r = b + \underbrace{\theta q(\theta) \left[\frac{w(\theta) - w_r}{r + \delta + \chi} \right]}_{\triangleq \rho}. \quad (6)$$

The variable ρ denotes the premium commended by workers over the flow value b of being unemployed. The expression can be rearranged so as to define the indifference condition for workers across submarkets $w(\theta) = w_r + \rho(r + \delta + \chi) / \theta q(\theta)$. The condition above shows the positive relationship between wages and the vacancy filling rate typical of directed search models (e.g., Moen, 1997; Acemoglu and Shimer, 1999). Conversely, wages and the job finding rate are negatively related: workers search in submarkets with low wages only if they have a higher probability to find a job. As wages approach the value of leisure, the gains derived from being employed vanish and the arrival rate of jobs diverges to infinity.

3.2 Firm policies

Consider a firm of *age* a . Its value Π depends on two state variables: the current level of employment ℓ_a and the *cumulated* wage bill $W_a \triangleq \int_0^a e^{-\chi(a-s)} q(\theta_s) v_s w(\theta_s) ds$. Firms face the adjustment cost function $C(v)$, which is an increasing and strictly positive function of the number of vacancies posted. They solve the following problem:

$$\Pi(\ell_a, W_a; z) \triangleq \max_{\{\theta_s, v_s, \mathbb{I}_s\}} \int_a^\infty e^{-(r+\delta)(s-a)} [R(\ell_s, \mathbb{I}_s; z) - W_s - C(v_s) - f - \mathbb{I}_s f_X] ds$$

$$s.t. \dot{\ell}_s = q(\theta_s) v_s - \chi \ell_s; \tag{7}$$

$$\dot{W}_s = q(\theta_s) v_s w(\theta_s) - \chi W_s; \tag{8}$$

$$w(\theta_s) = w_r + \frac{\rho}{\theta_s q(\theta_s)} (r + \delta + \chi). \tag{9}$$

The firm chooses the labor market segment θ_s in which it wishes to recruit, and the mass v_s of new vacancies to be created at age s . It also makes an export decision, i.e., it sets the export dummy \mathbb{I}_s to either zero or one. The firm's problem is subject to three constraints. The first constraint (equation (7)) represents the law of motion of firm size: vacancies are filled at the rate $q(\theta_s)$ and jobs are destroyed at the attrition rate χ . Equation (8) describes the law of motion of the cumulated wage bill: at each instant, random separation shocks lower the wage bill by the amount χW_s , while new hires $q(\theta_s) v_s$, who are paid the wage $w(\theta_s)$, add to the total wage bill. Equation (9) is a reformulation of the indifference condition (6) derived above.

As explained before, the cumulated wage bill W does not affect future decisions because it is sunk. Expected profits can therefore be decomposed as follows

$$\Pi(\ell_a, W_a; z) = \Psi(\ell_a; z) - \frac{W_a}{r + \delta + \chi} - \frac{f}{r + \delta},$$

which allows us to write the value of the firm as the solution of the following Hamilton-Jacobi-Bellman (HJB) equation

$$(r + \delta) \Pi(\ell_a, W_a; z) = \max_{\{v_a, \theta_a, \mathbb{I}_a\}} \left\{ R(\ell_a, \mathbb{I}_a; z) - W_a - C(v_a) - f - \mathbb{I}_a f_X + \frac{\partial \Psi(\ell_a, \mathbb{I}_a; z)}{\partial \ell_a} \dot{\ell}_a - \frac{\dot{W}_a}{r + \delta + \chi} \right\}. \tag{10}$$

Eliminating the terms including W and replacing the law of motions (7) and (8) yields

$$(r + \delta) \Psi(\ell_a; z) = \max_{\{v_a, \theta_a, \mathbb{I}_a\}} \left\{ \begin{aligned} & R(\ell_a, \mathbb{I}_a; z) - C(v_a) - \mathbb{I}_a f_X \\ & + \frac{\partial \Psi(\ell_a, \mathbb{I}_a; z)}{\partial \ell_a} [q(\theta_a) v_a - \chi \ell_a] - \frac{w(\theta_a)}{r + \delta + \chi} q(\theta_a) v_a \end{aligned} \right\}. \tag{11}$$

Recruitment policy. The policy functions are derived by maximizing the simplified Bellman equation (11). Remember that, in each period, a firm chooses the tightness of the submarket in which it recruits along with the number of vacancies. The first order condition with respect to v reads

$$\frac{C'(v_a)}{q(\theta_a)} = \frac{\partial \Psi(\ell_a, \mathbb{I}_a; z)}{\partial \ell_a} - \frac{w(\theta_a)}{r + \delta + \chi}. \quad (12)$$

Quite intuitively, the expected marginal cost of hiring an additional worker, $C'(v_a)/q(\theta_a)$, should be equal to the worker's shadow value, $\partial \Psi(\ell_a; z)/\partial \ell_a$, minus the discounted wage bill, $w(\theta_a)/(r + \delta + \chi)$.

Maximizing the objective function with respect to θ yields

$$\frac{\partial \Psi(\ell_a, \mathbb{I}_a; z)}{\partial \ell_a} q'(\theta_a) = w'(\theta_a) \frac{q(\theta_a)}{r + \delta + \chi} + w(\theta_a) \frac{q'(\theta_a)}{r + \delta + \chi}. \quad (13)$$

By varying θ , the firm affects the vacancy filling rate and thus the extent to which it can benefit from the shadow value of a filled vacancy. At the same time, changing θ also changes expected wage costs, both because a different choice of labor market segment θ requires the posting of a different wage and because variation in the job fill rate implies variation in the likelihood that the posted wage actually needs to be paid. In equilibrium, the two marginal effects must be identical. Combining (12) and (13), we obtain

$$\theta_a = \frac{1 - \eta}{\eta} \frac{\rho}{C'(v_a)}, \quad (14)$$

where η denotes the elasticity of the matching function.

The relationship between θ_a and v_a does not depend on the (endogenous) export status \mathbb{I}_a . The sign of the relationship is determined by the curvature of the recruitment cost function. When vacancy costs are convex, i.e., $C''(v_a) > 0$, firms wishing to post more vacancies search in labor markets characterized by higher tightness (lower θ_a). Since wages are decreasing in market tightness, we can conclude that firms with larger adjustment needs (higher v_a) pay higher wages. Thus, if vacancy costs are convex, the model replicates the positive empirical correlation between firm growth and wages paid to new hires. This result is intuitive: given that recruitment costs increase over-proportionately, firms that wish to hire many workers find it profitable to post higher wages in order to raise their job filling rates.

Proposition 1 (Wage-Size Link) *If recruitment costs are strictly convex, firms wishing to expand employment faster post higher wages. If, additionally, recruitment costs are isoelastic, firms with larger steady state employment levels create more vacancies and post higher wages.*

These effects are bigger, the greater the degree of convexity. Conversely, if recruitment costs are strictly concave, faster growing and larger firms post lower wages.

Proof. The first part of the Proposition is shown in the text. To prove the second part, note that steady state employment of the firm is given by $\bar{\ell} = q(\bar{\theta}) \bar{v}/\chi$ and, hence, $(\partial \bar{\ell}/\partial \bar{v})(\bar{v}/\bar{\ell}) = -\eta(\partial \bar{\theta}/\partial \bar{v})(\bar{v}/\bar{\theta}) + 1$. When the cost function has a constant elasticity $C'(v)v/C(v) \equiv \alpha$, (14) implies $(\partial \bar{\theta}/\partial \bar{v})(\bar{v}/\bar{\theta}) = 1 - \alpha$, and so $(\partial \bar{\ell}/\partial \bar{v})(\bar{v}/\bar{\ell}) = 1 - \eta(1 - \alpha) > 0$. The sign follows when $C(v)$ is convex, i.e., $\alpha > 1$. ■

In order to capture the well documented correlation between firm size and wages, we will hereafter restrict our attention to convex cost functions.²¹ The empirical literature supports this assumption. Direct empirical evidence is provided by Merz and Yashiv (2007), who estimate a structural model using US data and show that both labor and capital adjustment costs are strongly convex. Similarly Manning (2006) using UK data finds evidence of convex labor adjustment costs. Besides these findings providing direct support to the convexity assumption,²² Davis et al. (2013) find that US firms grow through a smooth process and that, as predicted by our model, faster growing firms fill their vacancies quicker.

Export status. The decision to export depends not only on the productivity, but also on the size (and, thus, on the age) of the firm. Young productive firms start small but gradually build up their work force until exporting a share of their output covers the fixed costs required to access the foreign market. They choose the exporting status that maximizes current revenues net of fixed costs,

$$\mathbb{I}_a(z) = \arg \max_{\mathbb{I}_a \in \{0,1\}} \{R(\ell, \mathbb{I}_a; z) - \mathbb{I}_a f_X\}.$$

The solution to this problem implies that there exists a size threshold $\ell^X(z)$, which makes firms indifferent between exporting and not exporting

$$\ell^X(z) = \frac{1}{z} \left(\frac{f_X}{\left(\frac{Y}{M}\right)^{\frac{1}{\sigma}} \left[(1 + \tau^{1-\sigma})^{\frac{1}{\sigma}} - 1 \right]} \right)^{\frac{\sigma}{\sigma-1}}, \quad (15)$$

so that firms featuring $\ell_a(z) > \ell^X(z)$ will be exporters. Forward-looking future exporters build up employment before they reach the age $a_X(z) \triangleq \inf \{a : \mathbb{I}_a(z) = 1\}$ at which they enter

²¹If $C''(v_a) = 0$, there is no link between the number of vacancies that a firm wishes to post and the labor market it selects, and, by (6), there would not be any wage dispersion.

²²Shimer (2010) proposes a theoretical microfoundation of convexity in labor adjustment costs. With concave revenues functions, the opportunity cost of reallocating workers from production tasks to recruitment tasks is convex in the size of the adjustment.

the foreign market. Optimal hiring ensures that employment grows smoothly over time. In particular, recruitment intensity does not jump when a firm starts exporting. By contrast, the share of domestic sales in total sales falls discretely at age a_X to make room for exports.

Note that the critical size $\ell^X(z)$ is decreasing in the firm's productivity level z . As we will see below, firms with higher productivity have higher employment growth rates at all ages. This means that they start exporting earlier than less efficient firms. The property of our model, that export status is a function of productivity z and age a rationalizes the overlap in the productivity distribution of exporters and non-exporters observed in the data (e.g. Roberts and Tybout, 1997; Bernard et al., 2003).

Dynamic conditions. We now derive the dynamic conditions governing the evolution of firm size. The following parametric assumptions provide tractability:

Assumption 1 *Vacancy costs are isoelastic, $C(v) = v^\alpha$, with $\alpha > 1$.*

Assumption 2 *The matching function is Cobb-Douglas, $q(\theta) = A\theta^{-\eta}$, with $\eta \in (0, 1)$.*

Solving the HJB equation (11), we obtain the equilibrium employment path and the dynamics of firm size and wage distribution.

Proposition 2 (Firm Employment Growth) *Under Assumptions 1 and 2, the optimal employment schedule of any given firm satisfies*

$$\left(\frac{\dot{\ell}_a + \chi \ell_a}{\xi_0}\right)^{\xi_1} \left(r + \delta + \chi - \xi_1 \frac{\ddot{\ell}_a + \chi \dot{\ell}_a}{\dot{\ell}_a + \chi \ell_a}\right) = \frac{\eta}{\rho} [R_1(\ell_a, \mathbb{I}_a; z) - w_r], \quad (16)$$

with $\xi_0 \triangleq A^{1+1/\xi_1} \left[\left(\frac{1}{\eta} - 1\right) \frac{\rho}{\alpha}\right]^{\frac{1}{\alpha-1}} > 0$ and $\xi_1 \triangleq \frac{1-\eta}{\eta+1/(\alpha-1)} > 0$. The optimal solution to (16) is pinned down by the boundary conditions (i) $\ell_0 = 0$, and (ii) $\lim_{a \rightarrow \infty} \ell_a(z) = \bar{\ell}(z)$ with²³

$$\left(\frac{\chi \bar{\ell}(z)}{\xi_0}\right)^{\xi_1} = \frac{\eta}{\rho} \left[\frac{R_1[\bar{\ell}(z), \mathbb{I}(\bar{\ell}(z), z); z] - w_r}{r + \delta + \chi}\right]. \quad (17)$$

The boundary condition for firms that eventually become exporters is given by the smooth pasting condition: $\lim_{\ell_a \rightarrow \ell_z^-} \dot{\ell}_a(z) = \lim_{\ell_a \rightarrow \ell_z^+} \dot{\ell}_a(z)$.

Proof. See Appendix A.1. ■

²³A solution always exists and is unique since the LHS is increasing in $\bar{\ell}$ and has function values in $(0, \infty)$, while the RHS is decreasing and takes values in $[-w_r \eta / \rho (r + \delta + \chi), \infty)$.

According to (17), marginal revenues $R_1(\cdot)$ converge to a limit that is higher than the reservation wage w_r . This is because workers have a strictly positive turnover rate $\chi > 0$ and so need to be replaced through costly recruitment. This drives a wedge between the opportunity cost of employment and the productivity of the marginal worker.

Equation (17) also shows that more productive firms converge to larger sizes (since $R_1(\cdot)$ is increasing in z). Moreover, firms that will end up being exporters have larger size conditional on age than non exporters. Hence, while the firm size distribution is continuous in firm age a , it exhibits a discontinuity in the productivity space, as firms with $z \geq z_X^*$ will be larger at all ages. Ceteris paribus, asymptotic firm sizes are lower the higher the value of unemployment benefits, or the less efficient the matching process. Finally, firms converge to larger sizes the bigger σ is, since this reduces monopoly power.

To characterize the equilibrium wage policy for each firm, notice that the equilibrium job finding rate $\theta q(\theta)$ can be expressed as $\left(\left[\dot{\ell}_a(z) + \chi \ell_a(z) \right] / \xi_0 \right)^{-\xi_1}$.²⁴ Then, the worker indifference condition (9) implies that

$$w_a(z) = w_r + \left(\frac{\dot{\ell}_a(z) + \chi \ell_a(z)}{\xi_0} \right)^{\xi_1} (r + \delta + \chi)(w_r - b). \quad (18)$$

By equation (7), this expression shows that search frictions lead to a markup of wages above the reservation wage and that this markup is proportional to the adjustment needs of a firm since $q_a(z) v_a(z) = \dot{\ell}_a(z) + \chi \ell_a(z)$. Equation (18) displays a growth and a size premium. A higher efficiency of the search technology lowers those premia, as higher A implies high ξ_0 . A higher degree of convexity α in the adjustment cost function leads to a higher value of ξ_1 and makes wages more responsive to firms' adjustment needs. The higher the effective discount rate $r + \delta + \chi$, the higher the premium as firms find it even more worthwhile to post higher wages to fill vacancies faster. International trade affects the distribution of wages by affecting the distribution of firm-level adjustment needs. As we will see below, lower trade costs lead to a more skewed distribution of firm sizes and growth rates, thereby altering the distribution of $\dot{\ell}_a(z) + \chi \ell_a(z)$ and hence that of wages.

Note that (18) describes wages of workers hired at a firm of age a . However, the firm employs workers hired throughout its history, possibly at different wages. This generates *within-firm* wage inequality: as adjustment needs change over time so do wages paid to new hires.

²⁴See equation (41) in the Appendix.

3.3 General Equilibrium

Having characterized firms' policies, we now close the model. We need to determine the equilibrium productivity cutoffs z_D^* and z_X^* , along with aggregate output and the unemployment rate. Recalling that new firms draw their productivity from the distribution $G(z)$, the equilibrium density of the productivity distribution is $\mu(z) \triangleq g(z) / [1 - G(z_D^*)]$ for all $z \geq z_D^*$; and the share of exporting firms is given by $\varrho < 1$. Average output per firm Y/M is given by the accounting identity

$$\frac{Y}{M} = \left[\frac{1}{1 + \varrho} \int_{z_D^*}^{\infty} \left((1 + \mathbb{I}_{\{a; z\}} \tau^{1-\sigma})^{\frac{1}{\sigma}} (z \ell_a(z))^{\frac{\sigma-1}{\sigma}} \delta e^{-\delta a} da \right) \mu(z) dz \right]^{\frac{\sigma}{\sigma-1}}, \quad (19)$$

where employment $\ell_a(z)$ of a firm of age a and productivity z is consistent with the optimality conditions described in Proposition 2.²⁵ Average output Y/M is a shifter of the revenue function (5), and thus a key equilibrium object driving firm behavior.

In contrast to Melitz (2003) (or to the one-period model discussed below), profits are not log-linear in productivity. Thus, the usual result that the two cutoffs z_X^* and z_D^* are multiples of each other does not hold anymore. Instead, we have to directly compute revenues and verify that the zero cutoff profit (ZCP) conditions, which ensure that the marginal domestic and exporting firms exactly break even, are satisfied. The same holds for the free entry (FE) condition which ensures that entry of new firms occurs until expected profits are exactly identical to the entry costs $f_E/(r + \delta)$.

For given recruitment policies, discounted profits are easily computed reinserting equations (11) and (12) into the definition of $\Pi(\cdot)$ to obtain

$$\begin{aligned} \Pi(0, 0; z) &= \frac{1}{r + \delta} \left[\frac{C'(v_0(z))}{q(\theta_0(z))} \dot{\ell}_0(z) - C(v_0(z)) - f - e^{-(r+\delta)a_X(z)} f_X \right] \\ &= \frac{1}{r + \delta} \left[(\alpha - 1) v_0(z)^\alpha - f - e^{-(r+\delta)a_X(z)} f_X \right]. \end{aligned} \quad (20)$$

where $a_X(z) \triangleq \inf \{a : \mathbb{I}_a(z) = 1\}$ is the age at which firm z enters the foreign market.²⁶ Equation (20) enables us to solve for the domestic cutoff z_D^* as the zero cutoff profit condition (ZCP) reads $\Pi(0, 0; z_D^*) = 0$: startups have zero employment and thus no promised wage, i.e., $\ell_0 = W_0 = 0$. In turn, the export productivity cutoff z_X^* is determined by the condition, $z_X^* = \inf \{z : \bar{\ell}(z) \geq \ell^X(z)\}$, according to which the marginal exporter is the least productive firm

²⁵The expression for aggregate employment takes into account that firms are destroyed each period at the Poisson rate δ .

²⁶When the firm always remains a domestic producer, $a_x = +\infty$ and the last term in (20) vanishes.

reaching the export threshold size $\ell^X(z)$ defined in (15). The free entry condition is satisfied when $(1 - G(z_D^*)) \int_{z_D^*}^{\infty} \Pi(0, 0; z) \mu(z) dz = f_E / (r + \delta)$. Since $\rho = w_r - b$, the ZCP and the free entry condition along with (19) provide us with three equations for the three unknowns $\{Y/M, w_r, z_D^*\}$. The final closure of the model requires the determination of the mass of firms M and the unemployment level. Since $v(\omega)/\theta(\omega)$ job seekers are needed to meet the recruitment needs of firm ω , aggregating over all firms we find that the aggregate number of job seekers reads

$$S = \frac{M}{1 + \varrho} \int_{z_D^*}^{\infty} \left(\int_0^{\infty} \frac{v_a(z)}{\theta_a(z)} \delta e^{-\delta a} da \right) \mu(z) dz. \quad (21)$$

Aggregate employment L can be computed in a similar way to obtain the equilibrium rate of unemployment $U = S/(S + L)$ and, assuming an inelastic labor supply, the mass of firms such that $S + L$ equals the size of the population.

4 A One-Period Variant of the Model

We have seen that the effect of international trade on the distribution of wages is driven by the distribution of firms' hiring needs. With convex adjustment costs, firms smooth their recruitment over time. Thus, a dynamic perspective is crucial for a *quantitative* assessment of the model. However, to build intuition, we analytically illustrate key model mechanisms using a framework in which firm adjustment happens within one single period.

4.1 Problem of the firm

Besides assuming that firms adjust within one period, the other deviations from the setup of Section 3 is to set the value of leisure b to zero. The timing is such that at the beginning of the periods all workers look for a job. Search is as described in the previous section. Thus, at the end of the period, a fraction $\theta q(\theta)$ of workers in a given submarket is employed and produces output. There is no discounting within the period. The expected wage income of a job seeker in market θ is given by $W = \theta q(\theta) w(\theta)$ so that we obtain the indifference condition

$$w(\theta) = \frac{W}{\theta q(\theta)}, \quad (22)$$

which is the counterpart of (9). As in the dynamic model, wages are a negative function of tightness as workers trade off a higher employment probability against a lower wage.

Firms post vacancies and wages at the beginning of the period; they fill the share $q(\theta)$ of

the announced jobs, and their end of period employment is $\ell = q(\theta)v$. Firm revenues are again given by (5). Inserting the worker indifference condition and substituting for ℓ , the problem of the firm reads

$$\pi(z) = \max_{\{\theta, v, \mathbb{I}\}} R(q(\theta)v, \mathbb{I}; z) - \frac{W}{\theta}v - C(v) - f - \mathbb{I}f_X. \quad (23)$$

The first-order condition with respect to v yields $R_\ell(\cdot)q(\theta) = W/\theta + C'(v)$ and the one with respect to θ yields $R_\ell(\cdot)q'(\theta) = -W/\theta^2$. Together these first order conditions imply

$$\theta = \frac{1 - \eta}{\alpha\eta} v^{1-\alpha} W, \quad (24)$$

which is identical to condition (14) in the dynamic model (with W being replaced by $\rho = w_r - b$). Firms posting more vacancies choose lower levels of θ (i.e., higher market tightness) and therefore post higher wages. Since $\ell = q(\theta)v$, larger firms pay higher wages.

4.2 Distribution of wages across firms

Keeping Assumptions 1 and replacing Assumption 2 by $q(\theta) = \min\{A\theta^{-\eta}, 1\}$ with $\eta \in (0, 1)$, we now characterize the distributions of wages, employment and profits.²⁷ We relate variables across submarkets with the help of a representative firm whose productivity \tilde{z} is such that its optimal price in the non-exporting state equals one, i.e., $p_D(\tilde{z}) = 1$. Notice that firms with productivity \tilde{z} can actually be exporters. Hence, the associated variables $\tilde{\ell}$, $\tilde{\theta}$ and profits $\tilde{\pi}$ are constructs which are not necessarily observed in equilibrium. We will alternatively refer to \tilde{z} as the productivity of the representative firm or average productivity. As shown in Appendix A.2, this normalization allows us to derive the following wage schedule:

$$\ln w(z) = \ln\left(\frac{\eta(\sigma-1)}{\sigma}\right) + \underbrace{\left(\frac{\sigma-1-\beta}{\sigma-1}\right)}_{\text{Productivity effect}} \ln z + \underbrace{\frac{\beta}{\sigma-1}}_{\text{Avg. efficiency}} \ln \tilde{z} + \underbrace{(\sigma-1-\beta) \ln(1 + \mathbb{I}(z)\tau^{1-\sigma})}_{\text{Export status effect}}, \quad (25)$$

where β is a combination of parameters defined in (49). Since $\beta \in (0, \sigma - 1)$, log-wages are increasing in firm productivity. The elasticity of wages with respect to z is constant and equal to $1 - \beta/(\sigma - 1)$. That elasticity is declining in α , the degree of convexity of the adjustment cost function. In the absence of search frictions, $\eta = 1$, or with linear adjustment costs, $\alpha = 1$, we have $\beta = \sigma - 1$. Then the wage schedule collapses to $\ln w(z) = \ln([\sigma - 1]/\sigma) + \ln \tilde{z}$ and

²⁷We will focus on equilibria where $\theta q(\theta) < 1$ in all submarkets.

wage dispersion disappears.

The wage schedule has two other components. First, when the efficiency of the representative firm \tilde{z} increases, the labor market becomes more competitive, and all firms must pay higher wages. Second, in order to serve the export market, exporting firms are required to reach a higher equilibrium size. This gives rise to an export wage premium as firms grow to a larger size by posting higher wages.

4.3 Equilibrium

Domestic and export market entry. Profits net of fixed costs are log-linear in z ; see Appendix A.3 for a proof. More precisely, taking the ratio of operating profits of firm z and of firm \tilde{z} yields

$$\pi(z) + f + \mathbb{I}(z) f_X = (1 + \mathbb{I}(z) \tau^{1-\sigma})^{\beta/(\sigma-1)} \left(\frac{z}{\tilde{z}}\right)^\beta [\tilde{\pi} + f]. \quad (26)$$

Evaluating (26) for the marginal domestic producer z_D^* yields the zero cutoff profit (ZCP) condition

$$(ZCP) : \tilde{\pi} = f \left[(\tilde{z}(z_D^*)/z_D^*)^\beta - 1 \right], \quad (27)$$

where we account for the dependence of \tilde{z} on z_D^* through

$$\tilde{z}(z_D^*) = \left[\frac{1}{1 + \varrho} \int_{z_D^*}^{\infty} z^\beta [1 + \mathbb{I}(z) \tau^{1-\sigma}]^{\beta/(\sigma-1)} \mu(z) dz \right]^{1/\beta}; \quad (28)$$

see Appendix A.3 for details. In the absence of search frictions, we would have $\beta = \sigma - 1$ and our ZCP would be identical to that in Melitz (2003). By contrast, in our model there is no ZCP for exporters. We identify the export cutoff z_X^* by using the indifference condition $\pi(z_X^*, \mathbb{I} = 0) = \pi(z_X^*, \mathbb{I} = 1)$. Without loss of generality, one can view the indifferent firm z_X^* as serving the domestic market only. Using (26), we obtain

$$\frac{z_X^*}{z_D^*} = \left(\frac{f_X}{f}\right)^{1/\beta} \left[(1 + \tau^{1-\sigma})^{\beta/(\sigma-1)} - 1 \right]^{-1/\beta} \geq 1. \quad (29)$$

The two cutoffs are positively related in equilibrium and, as one might expect, the productivity premium of the marginal exporter z_X^*/z_D^* is increasing in export fixed costs f_X relative to domestic fixed costs f , and in the iceberg trade factor τ .²⁸

²⁸In the absence of labor market frictions or convex adjustment costs (i.e., $\eta = 1$ or $\alpha = 1$, which both imply $\beta = \sigma - 1$), the relationship collapses to $z_X^*/z_D^* = (f/f_X)^{-1/(\sigma-1)} \tau$ as in the standard Melitz (2003) model.

Free entry condition. The free entry condition ensures that entry occurs until expected profits are exactly identical to the entry costs f_E , hence $E[\pi(z)] = f_E/[1 - G(z_D^*)]$. In equation (61) of Appendix A.4, we show how expected profits $E[\pi(z)]$ and profits of the representative firm $\tilde{\pi}$ are connected. This allows us to write the following free entry (FE) condition,

$$(FE) : \tilde{\pi} = \frac{f_E + \{1 - G[z_X^*(z_D^*)]\}(f_X - f)}{2 - G(z_D^*) - G[z_X^*(z_D^*)]}. \quad (30)$$

Product market equilibrium. Using the ZCP condition and the free entry condition (30), we can now determine product market equilibrium in $(\tilde{\pi}, z_D^*)$ -space. Existence of an equilibrium is guaranteed if $f_X < f_E$ and $\sigma > 1 + \alpha$.

Proposition 3 (Equilibrium) *If $f_X < f_E$ and $\sigma > 1 + \alpha$, the ZCP condition (27) and the free entry (FE) condition (30) uniquely determine the domestic cutoff z_D^* . The export cutoff z_X^* and the productivity of the representative firm \tilde{z} follow from equations (29) and (28).*

Proof. See Appendix A.5. ■

Value of search and welfare. Since W is average labor income and we have normalized the price index $P = 1$, the value of search W is a measure of welfare. Using the profit function and the ZCP condition (27), one obtains

$$W = \left[\frac{K}{f} \tilde{z}^\gamma (z_D^*)^\beta \right]^{\frac{1-\eta}{\eta} \frac{\alpha-1}{\alpha}}, \quad (31)$$

where γ , β , and K are all positive constants²⁹. So, an increase in the productivity of the marginal domestic producer and/or of the representative firm raises the value of search. Quite intuitively, as firms become more efficient, the zero cutoff profit and free entry conditions are reestablished through an increase in labor costs.

4.4 The impact of trade liberalization

The selection effect. In a first step, we study the effect of lower τ on the productivity of the representative firm, \tilde{z} . Under the conditions stated in Proposition 3, the FE locus shifts down. To pin down the shift of the ZCP curve, however, a parameter restriction is needed since the effect of τ on \tilde{z} is generally ambiguous.

²⁹See equations (49), (57) and (58) in the Appendix.

Proposition 4 (Selection) *Under the assumptions that firms draw their productivity from a Pareto distribution and that $f_X > f$, trade liberalization has an unambiguously positive effect on the domestic cutoff z_D^* and \tilde{z} .*

Proof. See Appendix A.8. ■

Trade liberalization expands the market size of productive firms who can take advantage from easier access to the foreign market. It also hurts less productive firms, whose revenues may fall due to increased competition by efficient foreign competitors. As a consequence, less efficient firms shut down, while more efficient firms expand. In line with Melitz (2003), this selection effect drives up the productivity \tilde{z} of the representative firm as long as the additional output share lost in iceberg costs does not outweigh the productivity gains at the factory gate.

The reallocation of labor towards more efficient firms increases the value of search. This is easily established considering the ZCP condition $\pi(z_D^*; \tilde{z}, W) = 0$. Equation (50) in the appendix implies that $\pi(z_D^*)$ is *strictly* decreasing in W and *strictly* increasing in both \tilde{z} and z_D^* . Since a reduction in τ raises the productivity of the representative and marginal firms, W has to increase until the ZCP is satisfied again.

Effects on wage dispersion and employment. Since lowering τ increases \tilde{z} , the wage profile (25) suggests that all wages rise with trade liberalization. Moreover, lowering τ has a direct positive effect on the exporter wage premium. To see the effect of lower τ on wage inequality, we examine the variance of wages

$$var[\ln w(z)] = (\sigma - 1 - \beta)^2 \left\{ \frac{var[\ln z]}{(\sigma - 1)^2} + var[\ln(1 + \mathbb{I}(z)\tau^{1-\sigma})] + \frac{2cov[\ln z, \ln(1 + \mathbb{I}(z)\tau^{1-\sigma})]}{\sigma - 1} \right\}. \quad (32)$$

If either all firms export (i.e., $\mathbb{I}(z) = 1$ for all z), or no firm exports (i.e., $\mathbb{I}(z) = 0$ for all z), then $var[\ln w(z)] = (\sigma - 1 - \beta)^2 \left\{ var[\ln z] / (\sigma - 1)^2 \right\}$, which is lower than the expression in (32). Clearly, the term $var[\ln(1 + \mathbb{I}(z)\tau^{1-\sigma})]$ increases with the share of exporters when that share is low, but decreases when the share of exporters is high. Hence, wage dispersion reaches its maximum at some intermediate level of openness. The export wage premium generates an inverted U-shape relationship between inequality and trade. A similar result is derived by Helpman et al. (2010) with a different model where inequality arises because of assortative matching. In the next section we assess whether the inverted U-shape relationship continues to hold in a dynamic version of our model.

Finally, we turn to the effect of trade liberalization on employment. We show in Appendix

A.6 that equilibrium employment can be written as

$$L = \tilde{\theta}q(\tilde{\theta}) \left(\frac{\bar{z}}{\tilde{z}}\right)^{\beta\frac{\sigma}{\sigma-1}-1}, \quad (33)$$

where \bar{z} is a weighted average of productivity levels constructed similarly to the productivity of the representative firm \tilde{z} (see equation (65)).³⁰ The expression of L is made of two components. The first one, $\tilde{\theta}q(\tilde{\theta})$, is the job finding rate in the submarket chosen by the representative firm. It would be equal to the aggregate level of employment if all workers were applying to jobs with posted wages \tilde{w} . The second component is due to the allocation of workers across submarkets with different levels of tightness; this ‘composition’ feature is captured by the ratio of two different weighted means for z .

The relationship between trade and unemployment cannot be signed analytically, since it depends on two opposite forces. A negative *composition effect*: trade-induced selection increases the average efficiency and size of firms; in order for firms to serve a larger market they offer higher wages and a longer queue (lower θ), thus potentially increasing unemployment. A positive *efficiency effect* due to the increase in the value of search W : as trade increases average efficiency \tilde{z} , workers’ outside option W increases, thereby raising the indifference condition (22). In other words, for each contract w firms need to offer a higher job finding rate $\theta q(\theta)$ in order to attract workers, and thus $\tilde{\theta}q(\tilde{\theta})$ increases. In the particular cases where all or no firms export, the ambiguity resolves as the composition effect disappears and, due to the efficiency effect, all firms offer a higher job finding rate when trade costs fall. In the general case where only a subset of firms export, the composition effect is operative and the impact of trade on employment is ambiguous. Notice that, since a reduction in trade cost increases the share of exporters, the extensive margin produces an additional composition effect similar to the one discussed above. New exporters grow and serve the foreign market by offering higher wages and longer queues. The degree of convexity of the adjustment cost function plays a key role in shaping the employment effect of trade. If $\alpha = 1$, the composition effect vanishes since there is no dispersion of wages and queues. Then, trade liberalization leads to lower unemployment. If $\alpha > 1$, the more heterogeneous firms are, the stronger is the negative composition effect of trade on jobs.

³⁰In Appendix A.9, we show that, with Pareto productivity, (33) becomes $L = \tilde{\theta}q(\tilde{\theta}) \Lambda$, where Λ is a constant that depends solely on the exogenous parameters of the model.

5 Quantitative Analysis

We start by showing that the model can replicate key moments of the German economy in 1996. We analyze the outcome of the calibration and explain why it is qualitatively consistent with the following facts: (i) rapidly expanding firms fill their vacancies at a faster rate and pay higher wage; (ii) the productivity distributions of exporters and non-exporters overlap; (iii) within-firm wage inequality contributes to overall inequality. Then, performing a number of comparative statics exercises, we characterize the impact of trade liberalization as well as labor and product market reforms on residual inequality and unemployment.

Before taking the model to the data, we generalize it by allowing wages to vary with tenure. As already explained in Section 3, neither firms nor workers have specific preferences over the timing of payments because they are both risk neutral. Thus their decisions are unaffected by the introduction of a wage-tenure profile as long as expected labor earnings for new hires remain the same across specifications. This flexibility enables us to match the returns to tenure observed in the data. We follow a standard Mincerian approach and assume that log-wages are a function of tenure T through a linear and a quadratic term.

5.1 Calibration to German data

We fix a number of parameters using external sources, normalize those that determine levels only, and set others to match empirical counterparts. We chose the values of the remaining parameters to minimize the sum of squared differences between the model's prediction and actual moments.³¹

The four externally calibrated parameters are $\{\eta, \delta, \chi, r\}$. Where applicable, the estimates producing those parameter values are based on data provided by the Institute of Labour Market Research (IAB) in Germany and are, therefore, naturally compatible with the SIAB and LIAB data bases provided by the same agency and used for other moments in our quantitative exercise. For the elasticity of the matching function, we refer to Kohlbrecher et al. (2014) who estimate $\eta = 0.65$.³² The firm and job destruction rates are taken from Fuchs and Weyh (2010). These authors use the Establishment History Panel of the IAB for the period 2000 to 2006. The data base includes all plants in Germany with at least one employee subject to social security. We

³¹The algorithm for the numerical solution of the model is discussed in the Appendix of the working paper IZA DP No. 7960.

³²Kohlbrecher et al. (2013) present estimates of η based on the SIAB data base (which contains information about unemployment spells of workers) for the period 1993 to 2007. Controlling for workforce heterogeneity, they do not reject a constant returns to scale specification of the matching function.

use their empirical estimates to set the yearly plant exit rate $\delta = 5\%$ per year, and the yearly job destruction rate due to match dissolutions $\chi = 7\%$. We choose a yearly interest rate of 4%.

Table 4: Calibration: Baseline Equilibrium for 1996

External Parameters				
Parameters	Value	Interpretation	Source	
η	0.65	Elasticity matching function	Kohlbrecher et al. (2014)*	
δ	0.05	Firm destruction rate	Fuchs and Weyh (2010)*	
χ	0.07	Match destruction rate	Fuchs and Weyh (2010)*	
r	0.04	Annual interest rate	Standard	
Estimated Parameters				
Parameters	Value	Interpretation	Source	
ψ_1	1.900%	Tenure profile, linear term	LIAB data, Mincer regression	
ψ_2	-0.037%	Tenure profile, quadratic term	LIAB data, Mincer regression	
Calibrated Parameters				
Parameters	Value	Moment	Model	Data
Elasticity of substitution, σ	4.25	Median markup	30%	30%
Iceberg Costs, τ	1.53	Exports share among exporters	20%	20%
Unemployment benefits, b	0.35	Replacement rate	32.7%	33%
Fixed costs, f	1.22	Average firm size	25.5	27.6
Fixed export costs, f_x	0.59	Share of exporting firms	18.6%	18.2%
Fixed entry costs, f_E	6.95	Within-firm wage variance, % total	51.5%	50%
Shape parameter, κ	3.43	Average size exporters	102.9	96.6
Vacancy costs, α	3.18	Exporter wage premium	10%	10%
Matching function, A	3.18	Unemployment rate	9.9%	9.9%

Notes. When applicable, data refer to annual periodicity.

* Parameter estimates are based on German social security data provided by the IAB.

To introduce a data-disciplined wage-tenure profile, we estimate a standard Mincerian wage regression

$$\ln w_{i,j,t} = \psi_1 T_{i,j,t} + \psi_2 T_{i,j,t}^2 + \gamma \mathbf{X}_{i,t} + \delta \mathbf{Z}_{j,t} + \varepsilon_{i,j,t}, \quad (34)$$

where $w_{i,j,t}$ is the wage of worker i employed at some plant j at year t . The vector $\mathbf{X}_{i,t}$ collects worker-level controls such as dummy variables for 4 educational categories,³³ 5 age groups,³⁴ a gender dummy, an indicator for German nationality, and indicator variables for more than 300 occupations. The vector $\mathbf{Z}_{j,t}$ contains firm-level variables such as an exporter dummy, log employment, and a full array of plant fixed effects.³⁵ Here, we are interested in the tenure profile. We obtain $\hat{\psi}_1 = 0.019$ and $\hat{\psi}_2 = -0.00037$, with both coefficients different from zero at

³³These categories are: (i) no vocational training, no high school; (ii) high school and/or vocational training; (iii) university or technical college; (iv) missing educational information.

³⁴These groups are defined over the age intervals 18-25, 26-35, 36-45, 46-55, and 56-65 years.

³⁵The OLS regression draws on yearly linked employer-employee data (LIAB) for full-time male workers in the Western German manufacturing sector from 1996 to 2007. Observations are weighted using officially provided analytical weights such that the sample is fully representative. The number of observations is $N = 9497283$. Standard errors are robust and clustered at the plant-level. This regression yields an adjusted R^2 statistic of 75.23%.

the 0.1% level of significance. We use these coefficients to simulate the theoretical wage profiles. To compare the empirical estimates of column (4) to those implied by our model, we create 230 samples of simulated data, each comprising 5,000 firms and about 120,000 workers. We run regression (34) on our simulated data, and find the coefficients $\psi'_1 = 0.02$, $\psi'_2 = -0.00036$, both highly significant, and almost identical to the empirical estimates.³⁶

We calibrate the remaining nine parameters $\{\sigma, \tau, b; \alpha, \kappa, A, f, f_X, f_E\}$ to match important moments of the German economy for the year 1996. Three of them, τ, σ, b have natural counterparts in the data so they can be directly calibrated, each one matching a single relevant moment. As shown in Section 2, the median markup in 1996 is 30%, which matched to firms markup in the model allow us to calibrate the elasticity of substitution σ . Exporters' export sales as a share of their total sales is $\tau^{1-\sigma}/(1 + \tau^{1-\sigma})$ in the model.³⁷ Thus matching the average share of exports in total revenues of exporters of 20% observed in the data, we obtain the benchmark $\tau = 1.53$. For the parameter b , we use the replacement rate of 0.33 computed by the OECD.³⁸ Setting $b = 0.35$, we calibrate its ratio to the average wage and set it as close as possible to 0.33. Finally, we assume that the productivity distribution is Pareto with shape parameter κ and normalize, without loss of generality, the expected productivity to one by setting the minimum possible productivity $z_{\min} = (\kappa - 1)/\kappa$.

We simultaneously choose the remaining parameters, $v \equiv \{\alpha, \kappa, A, f, f_X, f_E\}$ so that the numerical steady-state solution of the model matches relevant statistics. The parameters are calibrated in order to minimize a loss function defined by the quadratic distance between the moments in the model and the targeted statistics. We define $\mathbf{m} = [m_1, \dots, m_6]$ as the vector of the empirical moments described above, and $y(v)$ as the vector of equilibrium model moments generated by some vector of parameters v . Our calibrated parameter vector is obtained solving numerically

$$\hat{v} = \arg \min_{v \in \Xi} [(y(v) - \mathbf{m}) \cdot W \cdot (y(v) - \mathbf{m})']$$

where W is the weighting matrix, a diagonal matrix with the squares of the data targets on the diagonal, $W_{ii} = 1/m_i^2$, and zero for all other entries. We calculate the following empirical moments from plant-level data (see the Data Appendix B for further details): (i) the average firm size is 27.5 employees; (ii) the share of exporting firms is 18.2%; (iii) the average size of exporting

³⁶The averaging procedure is required to deal with sampling error.

³⁷Note that the link between τ and the share of revenues realized in foreign countries is particularly straightforward. Since $R_X = (p_X q_X)/\tau = p_D q_D \tau^{1-\sigma} = R_D \tau^{1-\sigma}$, we have $R_X/(R_D + R_X) = \tau^{1-\sigma}/(1 + \tau^{1-\sigma})$.

³⁸The OECD summary measure is defined as the average of the gross unemployment benefit replacement rates for two earnings levels, three family situations and three durations of unemployment. For further details, see OECD (1994), The OECD Jobs Study (chapter 8) and Martin J. (1996).

firms equals 96.6 employees; (iv) the difference between average wages paid by exporters to those paid by non-exporters (the exporter wage premium) is 10.1%;³⁹ (v) the aggregate unemployment rate provided by the Federal Employment Agency is equal to 9.9% in 1996; (vi) the share of total wage variance attributable to the within-firm component is about 50%.

As shown in Table 4, our model is able to replicate these moments rather well. It is worth stressing that the original feature of our model, within-firm wage inequality generated by directed search, accurately matches its data counterpart. The only noticeable tension is with respect to the distribution of firm sizes, as the model slightly overestimates the average size of exporters. This suggests that the right-tail of the model’s distribution is somewhat thicker than the one in the data, a well known feature of the Pareto distribution (see, e.g., Head et al., 2014). The implied parameters values are plausible. The ad valorem tariff equivalent of trade costs (approximately 60%), is well in line with numbers discussed in Anderson and van Wincoop (2004). The shape parameter of the Pareto distribution, κ , is close to 3.4, the value found by Bernard et al. (2007).

5.2 Out-of-sample tests

Dynamic moments Our theory generates a positive link between worker turnover at the establishment level and the wages of new hires. While limitations of the LIAB data set make a direct test of this prediction impossible,⁴⁰ we can still obtain tentative estimates of the role of plant size and growth on hiring wages. Moreover, as an out of sample test, we show that the calibrated model produces firm level wage-growth correlations consistent with these estimates.

We define as a ‘new hire’ a worker i employed at some plant j at year t who has not been employed at that plant in year $t - 1$. We run a variant of the Mincer regression (5.1), but focus on the wages of newly hired workers $\tilde{w}_{i,j,t}$

$$\ln \tilde{w}_{i,j,t} = \iota_1 \ln E_{j,t} + \iota_2 \ln E_{j,t-1} + \gamma \mathbf{X}_{i,t} + \delta \mathbf{Z}_{j,t} + \varepsilon_{i,j,t}. \quad (35)$$

$E_{j,t}$ is total employment at establishment j that employs worker i at date t , vectors $\mathbf{X}_{i,t}$ and $\mathbf{Z}_{j,t}$ are defined as above.⁴¹ The estimates $\hat{\iota}_1$ and $\hat{\iota}_2$ are to be interpreted as conditional correlations

³⁹The exporter wage premium is estimated in Mincer regressions without controlling for firm productivity or size. It captures the average residual wage premium paid by exporters (i.e., controlling for observed worker characteristics). Therefore, it confounds the export status effect and the productivity effect highlighted in equation (25).

⁴⁰The LIAB data set reports plant employment at some reference date for each year, but does not give information on gross turnover. Moreover, the panel suffers from substantial attrition so that the number of continuing firms available is rather low.

⁴¹The only difference is that $\mathbf{X}_{i,t}$ contains measures of worker tenure.

and have no causal meaning. Next to (35), we also run regressions in which we suppress the lagged employment level, or in which we add establishment dummies $D_{j(i)}$.

Table 5: Mincer moments: Data versus model

	Data					Model averages	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\ln E_{j(i),t}$	0.138 (0.072)	0.057 (0.025)	0.160 (0.091)	0.014 (0.021)		0.015 (0.005)	
$\ln E_{j(i),t-1}$			-0.048 (0.074)	-0.003 (0.009)		-0.005 (0.001)	
Exporter status (0, 1)					0.021 (0.004)		0.020 (0.006)
<u>Additional controls</u>							
Establishment effects	NO	YES	NO	YES	YES		
Firm productivity	NO	NO	NO	NO	NO	YES	YES
Worker observables	YES	YES	YES	YES	YES	n.a.	n.a.
$adj.R^2$	0.52	0.85	0.75	0.87	0.82	n.a.	n.a.

Notes. Columns (1) to (4) report regression results on unbalanced panel of newly hired workers: N=3,511, number of plants 560; column (5) of all workers (new and incumbent) in the sample: N=45,087, number of plants 2,217; all data for 1996. Robust standard errors in parenthesis. All models include worker observables, region-year and industry-year effects as in (35). Columns (6) and (7) report averages (standard deviations in brackets) of estimated effects from 230 regressions on simulated residual wages, conditional on productivity (coefficients suppressed).

Regression model (1) in Table 5 yields a statistically significant size effect which is robust to adding establishment effects to the model (see column (2)).⁴² Columns (3) and (4), however, show that neither the contemporaneous nor the lagged employment levels are statistically significant when both included, regardless of whether establishment effects are added or not. The coefficients have the expected signs: a higher contemporaneous employment level increases wages, while a higher lagged level lowers them as adjustment needs are smaller. With establishment effects, the coefficients are very close to zero.⁴³ Disregarding the lack of statistical significance, these results imply that the wages of new hires increase in plant growth and in plant size.

We then use the simulated dataset described above to assess whether these findings are

⁴²Starting with Schmidt and Zimmermann (1991), the role of firm size for wages has been well-documented in German data, albeit usually in samples comprising both new and incumbent workers.

⁴³This pattern remains broadly robust if we vary the array of controls included in (35). Presumably, this disappointing outcome is jointly due to the low number of observations and to the fact that a negative correlation between $\varepsilon_{i,j,t}$ and employment would bias ι_1 towards zero. Also, note that time variation in $E_{j,t}$ is low and that we do not have any start-ups in the sample.

consistent with our calibrated model. We regress simulated log residual wages of newly hired workers on simulated current and lagged log employment levels (as well as on the level of productivity, the only time-invariant establishment characteristic in our model), and report the averages and standard deviations of the obtained coefficients in column (6). We find that both sizes and growth rates are correlated with wage offers but the coefficients are strikingly low, with an elasticity of 0.015% and -0.005% , respectively. In light of the limitations of our data set, it should not be surprising that such small correlations are difficult, if not impossible, to identify econometrically. Thus, the lack of conclusive empirical evidence does not contradict our model since its simulation is in line with a very weak link between firm size/growth and the wages of new hires.⁴⁴ Rather, we view the high fit between the simulated averages of our model and the coefficients obtained in actual data as an out-of-sample check of the validity of our framework.

Conditional exporter wage premium. Columns (5) and (7) report an additional out-of-sample check. We compare the exporter status effect implied by the model with the one obtained in the data.⁴⁵ As above, we simulate 230 samples of artificial data. We use the data to regress log residual wages on exporter status and productivity. We average across samples and find a coefficient of the exporter dummy that is equal to 0.020. This is again very close to the coefficient measured in the real data.

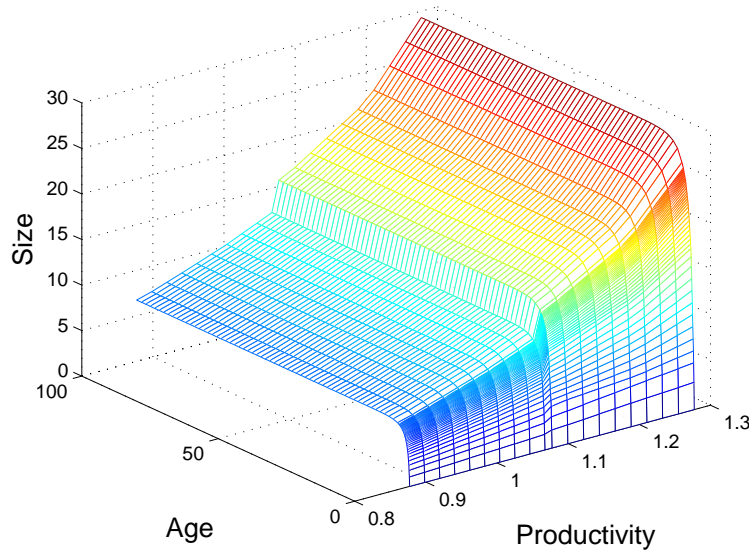
Size distribution. Figure 3 plots the cross-sectional distribution of firm employment as a function of firm-level age and productivity. It focuses on a subset which includes the marginal producer z_D^* and the marginal exporter z_X^* . Notice that the firm size distribution exhibits a discrete jump at the productivity cutoff z_X^* . By contrast, as a function of firm age, the size distribution is continuous. In our model, from the start of their existence, highly productive future exporters internalize that they will end up larger than non-exporters and they put on employment accordingly, even if they do not export yet. When they have reached the critical size (and age) of starting to export, foreign sales jump up and domestic sales fall, leaving overall sales (and employment) constant. This avoids the counterfactual prediction of the basic Melitz (2003) model where exporters and non-exporters are perfectly partitioned along the productivity dimension (e.g. Bernard et al., 2003). Impullitti et al. (2013) use the interaction between sunk export costs and idiosyncratic uncertainty to explain the existence of highly productive non-exporters. Eaton, Kortum and Kramarz (2011) introduce firm and market specific hetero-

⁴⁴A proper test would require a different procedure based on data containing detailed information about gross jobs flows at the firm level, a task that we leave to further research.

⁴⁵In the calibration, we have targeted the *unconditional* exporter wage effect.

ogeneity in entry costs and demand. Fajgelbaum (2013) sets up an economy with frictions to job-to-job transitions and fixed investment costs into exporting and show that firms are born small, accumulate workers gradually and enter the export market only when they have reached a sufficient size. We complement Fajgelbaum’s explanation by showing that a similar dynamic of firms entry into the export market can be obtained in an environment without on-the-job search, and it is generated by the combination of search frictions and convex adjustment costs.

Figure 3: Firm size as a function of productivity and age



The figure also shows that more productive firms grow faster. By equilibrium condition (14), this implies a higher vacancy filling rate. Thus directed search can explain the recent findings of Davis et al. (2013) according to which more productive firms fill their vacancies faster.⁴⁶ By contrast, in models with random matching, firms achieve higher growth rates by posting more vacancies. Moreover, introducing screening in a random matching environment, as in Helpman et al. (2010), would deliver the counterfactual prediction that high wage openings are filled through a lengthier selection process.

Wage distribution. We have chosen not to target the overall wage variance in our calibration because, as explained in Section 2, it is not possible to isolate the ‘pure’ firm component of wage dispersion in the data. Log wage variance due to the firm component in the decomposition of Table 1 is 2.9% on average in the period 1990-96, can be inflated by match effects and by

⁴⁶Unfortunately, our data do not contain information on vacancies, so we cannot directly target the correlation between hiring wages and vacancy filling rates.

rent sharing, as explained in Section 2. Hence, we have chosen not to target the overall wage variance in our calibration because it is not possible to isolate the ‘pure’ firm component of wage dispersion in the data. Nevertheless, although the pure firm effect is the only source of inequality in our economy, the model does a good job in generating a sizable variance of log-wages of 1.25%, thereby accounting for 43% of the residual wage dispersion attributable to firm fixed-effects in Card et al. (2013). In Table 6 below, we report the total wage dispersion attributable to firm fixed-effects in Card et al. (2013) for the periods 1990-96 and 2000-09 as a data reference point, although imperfect, and compare it with the model predictions generated by the set of reforms observed in those years.

The wages of new hires fall with firm age because younger firms grow faster, and in our labor market with competitive search, firms foster growth by posting better compensations. Thus workers with more seniority earn higher wages, as commonly observed in the data. Notice that within-firm inequality cannot be obtained using random search as in, e.g., Cosar et al. (2016). In that model, firms pay their employees equally because all wages are renegotiated at every point in time and this firm-specific wage falls as the firm closes in to its desired size. The importance of within-firm wage dispersion is documented by, among others, Haltiwanger et al. (2010), Bloom et al. (2015) for US data, Mueller et al. (2015) for UK data and Helpman et al. (2013) for Brazilian data. As can be seen in Table 2, our German data confirm the presence of substantial pay differentials within firms.

5.3 Equilibrium properties and policy evaluation

Taking our calibration as the baseline, we evaluate whether trade, labor and product market reforms can explain the changes in German labor market outcomes documented above. We first feed the model the changes in parameters implied by each reform one by one, in order to isolate their effects. We then compute the combined effect of all reforms. The objective of this exercise is to understand and quantify the effects of the different reforms on the dynamics of total residual wage dispersion and on its between/within-firm decomposition.

Table 6, shows the changes in the main moments between the two periods and the effects of each reform predicted by our model. We report the key facts highlighted in Section 2. Comparing 1996 to 2009, the share of exports in total sales of exporters, the share of exporting firms in the population, and the average size of exporters all increase, while the average size of exporters decreases. This suggests that standard Melitz-type trade-induced selection effects have been at work in this period.

Table 6: The impact of reforms

Moments	Data		Model		Model (2009)			
	1996	2009	1996	$\tau = 1.3$	$b = 0.23$	$A = 3.5$	$\sigma = 5$	Joint
Median markup, %	30	25	30	30	30	30	25	25
Exports share among exporters	20	29	20	29	20	20	20	29
Share of exporting firms, %	18.2	30	18.6	36	18.9	19.3	8.7	35
Average firm size	27.6	35.1	25.5	27.8	25	26.1	37.2	41.8
Average size exporters	96.6	89.6	102.9	66	98.5	103.4	326	107.4
Unemployment rate	9.9	7.8	9.9	8.73	9.2	9.2	14.5	11.8
Total wage variance (residual), %	2.9	5.3	1.25	1.26	1.35	1.19	2.28	1.94
Exporter wage premium, %	10	10	10	9.5	10.7	9.6	14	14.7
Within-firm wage variance, % total	50	43	51.5	53	54	56	44	45

Baseline values: $\tau = 1.53, b = 0.35, A = 3.36, \sigma = 4.25$.

The unemployment rate shows a marked decline while overall wage dispersion increases substantially. Wage dispersion comes from two sources both related to the firm-specific component of wages: wage dispersion in average wages across firms, the between-firm component, and dispersion among workers in any given firm, the within-firm component. Our between-within decomposition in Table 2 shows that most of the increase in inequality in the period of analysis is due to the between-firm component. Moreover, the total wage dispersion due to the firm component based on Card et al. (2013) decomposition experiences a rapid increase as well.

Trade liberalization. We lower variable trade costs τ so as to match the increase in the share of revenues derived from exports. Since the mapping between the two variables does not depend on any other parameters aside from σ , we directly infer that τ needs to decrease from 1.58 to 1.3 in order to generate the observed increase in exports share from 20 to 29 percent. Keeping all the other parameters constant, we re-simulate the model and compare its outcome with the actual changes documented in Tables 3 and 4.

Trade liberalization raises the share of exporting firms by increasing the survival cutoff z_D^* and reducing the export cutoff z_X^* . It also raises the reservation wage w_r . These results are in line with the selection effect of the one-period model: the expansion in market size induced by trade liberalization increases the demand for labor, thereby raising workers' outside option and forcing less competitive firms out of the market. Moreover, lower variable trade costs allow the most productive domestic firms to start exporting. As a result of these selection effects, Table 6 shows that the model captures qualitatively and in some cases even quantitatively several changes found in the LIAB data. First, it predicts that the share of exporting firms increases substantially from the benchmark 18% to 36%, a slightly bigger change than that observed in the data. It also reproduces the fall in the average size of exporters because the negative composition effect,

due to the decrease in the export threshold, dominates the increase in size among pre-reform exporters. This overall gain explains why average firm size adjusts in the opposite direction. The key result of this comparative statics is that the observed trade liberalization does not seem to affect neither the overall level of wage inequality nor its between-within firm breakdown.

Another interesting feature of the comparative statics exercise is the prediction that employment goes up. The impact on unemployment is particularly significant since it decreases from 9.8% to 8.7% solely because of trade liberalization, hence reproducing most of the drop in unemployment shown in the data.⁴⁷ This result, interpreted in the light of our findings in the one-period model discussed in Section 4.4, suggest that the *efficiency effect* of trade liberalization prevails. By increasing firm size, trade increases firm competition for workers, forcing them to offer higher job finding rates for each wage offer, thereby increasing aggregate employment.

To sum-up, decreasing τ from 1.58 to 1.3 explains most of the adjustments in firm size and export status as well as in aggregate employment. However, the degree of wage dispersion as measured by the standard deviation of log-wages and the decomposition into between and within-firm inequality remains almost flat. Also, the difference between the average exporter wage and the average non-exporter wage (the exporter wage premium) does not change much, while the data show an increase. This is not necessarily at odds with the one-period model because the exporter wage premium confounds the productivity effect and the export status effect in equation (25).

Hence, while reasonable changes in τ go a long way in explaining the observed reduction in the German unemployment rate from 1996 to 2007, trade appears to be of little relevance for the observed increase in residual wage dispersion. This suggests that other mechanisms are at work in our dynamic framework. One plausible explanation is that firms smooth the effect of trade-induced reallocations on wage dispersion. By contrast, in the one period model firms adjust immediately to the new post-liberalization optimal size, and this leads to a larger jump in the wage contract they offer.

Labor market deregulation. The first institutional change that we analyze is the reduction in unemployment benefits associated with the Hartz IV reform. The OECD estimates that the replacement rate in Germany was reduced by about 30% from 2001 to 2009, which applied to our benchmark benefit gives $b = 0.23$. Lowering b reduces the reservation wage w_r as well as the two cutoffs z_D^* and z_X^* . Intuitively, a reduction in benefits lowers workers' outside option, making survival easier for firms, allowing marginal non-exporters to enter the foreign market.

⁴⁷Interestingly, this is very close to the employment gain of about 440,000 workers that Dauth et al. (2014) attribute to increased trade in their econometric work.

In Table 6 we report the impact that unemployment benefits have on labor market outcomes.⁴⁸ Perhaps surprisingly, b has a smaller effect than τ on unemployment, which declines by less than three quarters of a percentage point. This is in line with the results in Launov and Waelde (2013). They estimate an equilibrium matching model with spell-dependent unemployment benefits and find that the Hartz IV reform reduced unemployment by 0.7 percentage points. The model also predicts that residual inequality increases with smaller b : since the lower bound of the wage distribution is pinned down by the reservation wage w_r , a reduction in benefits shifts the support of the wage distribution to the left thereby making it more dispersed. Finally, the reduction in the unemployment rate has a counterfactual effect on the between-within firm inequality split, increasing the share of inequality attributed to the within-firm component.

The Hartz III package of reforms focused on the Federal Employment Agency with the objective to increase the efficiency of job search. Fahr and Sunde (2009) estimate the effects of this reform and argue that it has increased search efficiency by between 5 and 10%. We model this by simulating the effects of a an increase in A , from 3.36 to 3.7. Not surprisingly, increasing matching efficiency lowers the intensity of search frictions, thereby reducing unemployment. The effect is quantitatively strong,⁴⁹ but the impact on inequality is counterfactual as better matching efficiency reduces wage dispersion. Improvements in the matching technology relax the trade off between wages and job filling rates. More productive firms resort less to wage incentives in order to raise their growth rates. Hence, the reforms aimed at improving the functioning of the public employment agency can explain part of the reduction in German unemployment but not the increase in inequality.

Product market deregulation. The other significant change over the period of interest relates to the ongoing process of European integration, most notably the single market program with its ambitious reforms of product market regulation. While the single market program presumably brought down trade costs between EU member states, it also led to deep *domestic* regulatory reform within each country. Indeed, Wölfl et al. (2009) document that the OECD index of product market regulation (PMR) intensity for Germany fell from 2 in 1998 to 1.37 in 2008, with two thirds of this change taking place by 2003. This corresponds to a 24% drop in the PMR intensity by 2003 and a 36% by 2008. Griffith et al. (2004) and (2010) provide empirical

⁴⁸The simulation of the Hartz IV reform has to be treated with caution because countries are symmetric in our model. This approximation is not too problematic for episodes of trade liberalization since they are generally implemented through multilateral agreements. By contrast, Germany was rather isolated in its push towards labor market deregulation, to the extent that it has sometimes been accused of promoting beggar-thy-neighbor policies.

⁴⁹Launov and Waelde (2013) set up a random search model with heterogenous workers and show that the change in matching efficiency implied by Hartz III explains about one third of the post-reform reduction in unemployment.

evidence that the deregulation reforms carried out under the EU Single Market Program in the early 1990s increased product market competition, as measured by a reduction in average sectorial profitability, in all major European economies. Using our firm level data we have computed the average and median markups for Germany in the period of interest. In Figure 2 we show that the markup, computed as profits share of revenues, has a median value of 30% in our benchmark year 1996, and it decreases to 28% in 2007 and to 25% in 2009, a trend in line with the empirical evidence for other European countries.

Following Blanchard and Giavazzi (2003), we posit that product market reforms (encompassing trade liberalization) increase competition, thereby decreasing profit margins. A reduced form way to implement this is to experiment with an increase in the elasticity of substitution. The drop in markup observed in the data between 1996 and 2009 implies an increase in the elasticity of substitution σ , from 4.25 to 5. Table 6 shows that, in spite of its relatively modest size, such a change has a significant impact on the economy. In particular, it increases both residual wage inequality and the share of inequality accounted for by the between firm channel. Overall residual inequality increases from 1.25% to 2.28% accounting for about most of the increase observed in the data where total wage variance due to the firm component increases from 2.9% in 1996 to 5.3% in 2009. Intuitively, a higher σ makes the mapping between productivity and optimal size steeper, as can be seen from (17). This effect is due to the role of demand elasticity in shaping the link between firms' productivity and their optimal size. Higher demand elasticity increases the size premium of more productive firms, thereby increasing the dispersion of firm size. Since wage inequality in our economy is generated by dispersion in firm size, higher product market competition increases firm-size dispersion and wage inequality. Moreover, these adjustments imply that recruitment becomes more competitive, which intensifies search frictions and pushes up the rate of unemployment. Interestingly, among all reforms only the increase in product market competition yields a decrease in the share of inequality attributable to the within-firm component, matching most of the decline observed in the data. This result is in line with recent findings by Bloom et al. (2015). Focusing on a new matched employer-employee data set covering all US firms in the period 1976-2012 they find that most of the observed increase in inequality can be attributed to rising dispersion between firms in the average wage they pay.

To the best of our knowledge, our paper is the first to uncover this interesting link between demand elasticity, firm size and wage dispersion. Admittedly, the structure of our model economy with monopolistic competition and CES preference is too simple to allow a proper identification of which among the many reforms we consider had a major impact on product market competition, thereby shaping the evolution of firm size dispersion and wage inequality.

ty. Under this market structure, firms market power cannot be affected by any change in the institutional environment. There is substantial empirical evidence that trade liberalization has pro-competitive effects via a reduction of markups at the sectorial and firm level.⁵⁰ In line with Krugman (1979), our model could be easily extended to embed a reduced-form representation of variable markups assuming that the elasticity of substitution is a function of firm size. Hence, trade liberalization would have pro-competitive effects which would spread both firm size and wage dispersion. Hence, although we cannot exclude that trade had a role in shaping the dynamics of inequality in Germany, a key message of our paper is that in order to fully assess this role we must move to an economy with variable markups. Unfortunately, modeling variable markups in open economies with firm heterogeneity and in general equilibrium is hard, even in a model with perfectly competitive labor markets. Melitz and Ottaviano (2008), offer a first step in this direction, setting up a partial equilibrium version of the Melitz model with variable markups obtained moving away from CES preferences. Recent contributions by Feenstra (2014) and Demidova (2016) have tried to extend the model to a general equilibrium set up. These considerations suggest that an important avenue for future research is to embed variable markups in our economy in order to carefully identify the effects of different policy changes on inequality, first among them the effect of trade liberalization.

Interactions between reforms. To take stock, trade liberalization can explain a substantial share of the adjustments in employment as well as in the cross-sectional distribution of firms characteristics. But its effect on residual inequality is rather marginal. Given that a similar conclusion holds for labor market reforms, the model singles out higher competition in *domestic* product markets as the main force behind the increase in residual inequality. Having determined the qualitative effects of each channel, we now assess whether their interaction can account for the changes observed in the data.

The results of this joint experiment is summarized in the last column of Table 6. Qualitatively, the combined policy changes generate responses in endogenous variables which are in line with the data, except for the unemployment rate which is predicted – counterfactually – to increase as a consequence of fiercer product market competition. Quantitatively, the model successfully matches about half of the changes in moments as shown in Table 6. It works best for export shares of exporters, the average size of exporters, and the share of within-firm wage inequality. It predicts an increase of overall inequality by about 50% (from 1.23 to 1.86%), while the data see an increase by 83% (from 2.9 to 5.3%).

⁵⁰See Feenstra and Weinstein (2016) and De Loecker, Goldberg, Khandelwal, and Pavcnik (2016) for recent contributions.

6 Conclusion

We build a model where firm dynamics and directed search on the labor market produce wage dispersion among homogenous workers. We use it to explore the effects of trade, product, and labor market reforms on residual inequality and unemployment. A one-period version of the model can be solved in closed form and provides an analytical characterization of the mechanisms linking trade and inequality. It generates an inverted U-shape relationship between trade and inequality which hinges on the presence of an export wage premium: trade liberalization increases inequality when trade costs are high and few firms pay the premium, but it reduces it when trade costs are low and most firms pay the premium. The effect of trade on jobs is also ambiguous and strictly dependent on the shape of adjustment costs.

We use German matched employer-employees data to calibrate the dynamic model and explore its properties numerically. Going beyond trade, we also study the roles of labor and product market reforms. The main mechanisms linking trade and labor market outcomes highlighted in the one-period model continue to provide intuition. Moreover, the interaction between wage posting and firm growth explains important firm-level regularities recently highlighted in the empirical literature. First, firms increase their rate of growth by posting higher wages and filling their vacancies faster. Second, productivity distributions of exporters and non-exporters show partial overlap. Third, wage dispersion occurs both between and within firms.

Matching key statistics allows us to use the model for a quantitative assessment of the impact of trade and institutional reforms on the German labor market. Focusing on the period 1996-2007 we find that neither the massive increase in German trade openness, nor the main features of the Hartz labor market reforms, can explain the sharp increase in residual wage dispersion observed in the data. By contrast, higher competition in the product market, nested into the model as an increase in demand elasticity, has a strong effect on inequality, potentially accounting for the whole increase in German wage dispersion. Finally, lower trade costs can account for a sizable fraction of the decline in unemployment observed in the data, in contrast to a general increase in product market competition which turns out to drive up unemployment.

Our analysis suggests several directions for future research. One possible extension would analyze more deeply the role of smooth firm growth in shaping the trade-inequality nexus, by comparing dynamic models to their static counterparts. Secondly, since our results suggest that wage dispersion is highly responsive to changes in demand elasticity, introducing endogenous markups could potentially strengthen the quantitative link between trade and inequality.

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A Proofs

A.1 Proof of Proposition 2

The only dynamic component of the optimality conditions is $\partial\Psi(\ell_a, \mathbb{I})/\partial\ell_a$. Directly differentiating its expression in (11) yields

$$(r + \delta + \chi) \frac{\partial\Psi(\ell_a, \mathbb{I}; z)}{\partial\ell_a} = R_1(\ell_a, \mathbb{I}; z) + \frac{\partial^2\Psi(\ell_a, \mathbb{I}; z)}{\partial\ell_a^2} [q(\theta_a)v_a - \chi\ell_a] ,$$

where we add the number of the independent variable as a subscript to denote its partial derivative. The expression above makes clear that $\partial\Psi(\ell_a, \mathbb{I})/\partial\ell_a$ is the shadow value of labor since it is equal to the discounted sum of marginal output. The term on the right hand side can be expressed as⁵¹

$$\begin{aligned} \frac{\partial^2\Psi(\ell_a, \mathbb{I}; z)}{\partial\ell_a^2} [q(\theta_a)v_a - \chi\ell_a] &= \frac{\partial^2\Psi(\ell_a, \mathbb{I}; z)}{\partial\ell_a^2} \dot{\ell}_a = \frac{d}{da} \left(\frac{\partial\Psi(\ell_a, \mathbb{I}; z)}{\partial\ell_a} \right) = \frac{d}{da} \left(\frac{C'(v_a)}{q(\theta_a)} + \frac{w(\theta_a)}{r + \delta + \chi} \right) \\ &= \frac{C''(v_a) \dot{v}_a q(\theta_a) - C'(v_a) q'(\theta_a) \dot{\theta}_a}{q(\theta_a)^2} + \frac{w'(\theta_a) \dot{\theta}_a}{r + \delta + \chi} . \end{aligned}$$

Reinserting this equality into the previous equation, we obtain

$$(r + \delta + \chi) \left[\frac{C'(v_a)}{q(\theta_a)} + \frac{w(\theta_a)}{r + \delta + \chi} \right] - \frac{C''(v_a) \dot{v}_a q(\theta_a) - C'(v_a) q'(\theta_a) \dot{\theta}_a}{q(\theta_a)^2} - \frac{w'(\theta_a) \dot{\theta}_a}{r + \delta + \chi} = R_1(\ell_a, \mathbb{I}; z) . \quad (36)$$

The dynamics condition is too intricate to be analyzed at this level of generality. This is why we impose the additional Assumptions A1 and A2. When recruitment costs are isoelastic, i.e., $C(v) = v^\alpha$, (14) is equivalent to $v_a^{\alpha-1} = (1 - \eta) \rho / (\eta \alpha \theta_a)$ and the dynamic equation (36) reads

$$(r + \delta + \chi) \frac{\alpha v_a^{\alpha-1}}{q(\theta_a)} + w(\theta_a) - \frac{\alpha(\alpha - 1) v_a^{\alpha-2} \dot{v}_a q(\theta_a) - \alpha v_a^{\alpha-1} q'(\theta_a) \dot{\theta}_a}{q(\theta_a)^2} - \frac{w'(\theta_a) \dot{\theta}_a}{r + \delta + \chi} = R_1(\ell_a, \mathbb{I}; z) . \quad (37)$$

Assumption A2 allows us to simplify this equation further by expressing analytically the slope \dot{v}_a of the vacancy schedule with respect to age. When the matching function is Cobb-Douglas, i.e., $q(\theta) = A\theta^{-\eta}$,

$$\dot{v}_a = - \frac{\dot{\theta}_a \theta_a^{-\frac{\alpha}{\alpha-1}}}{\alpha - 1} \left[\left(\frac{1}{\eta} - 1 \right) \frac{\rho}{\alpha} \right]^{\frac{1}{\alpha-1}} ,$$

and so

$$\frac{\alpha v_a^{\alpha-1}}{q(\theta_a)} \left[r + \delta + \chi - (\alpha - 1) \frac{\dot{v}_a}{v_a} + \frac{q'(\theta_a) \dot{\theta}_a}{q(\theta_a)} \right] = \left(\frac{1}{\eta} - 1 \right) \frac{\rho}{\theta_a q(\theta_a)} \left[r + \delta + \chi + \frac{\dot{\theta}_a}{\theta_a} (1 - \eta) \right] . \quad (38)$$

Reinserting (38) into (37) and using (??) to substitute $w'(\theta_a)$, we finally obtain

$$\frac{1}{\theta_a q(\theta_a)} \left(r + \delta + \chi + \frac{\dot{\theta}_a}{\theta_a} (1 - \eta) \right) = \frac{\eta}{\rho} [R_1(\ell_a, \mathbb{I}; z) - w_r] . \quad (39)$$

In order to solve this equation, we use the following change of variable $\vartheta_a \triangleq [\theta_a q(\theta_a)]^{-1} = A^{-1} \theta_a^{\eta-1}$ so that

$$\dot{\vartheta}_a = (\eta - 1) A^{-1} \theta_a^{\eta-2} \dot{\theta}_a = \frac{1}{\theta_a q(\theta_a)} \frac{\dot{\theta}_a}{\theta_a} (\eta - 1) .$$

⁵¹The third equality follows from (12).

Thus (39) is equivalent to

$$\vartheta_a (r + \delta + \chi) - \dot{\vartheta}_a = \frac{\eta}{\rho} [R_1(\ell_a, \mathbb{I}; z) - w_r] . \quad (40)$$

We wish to express (40) as an ODE in ℓ_a only. Straightforward algebra yields

$$\dot{\ell}_a + \chi \ell_a = q(\theta_a) v_a = q(\theta_a) \left[\frac{1}{\theta_a} \left(\frac{1}{\eta} - 1 \right) \frac{\rho}{\alpha} \right]^{\frac{1}{\alpha-1}} = \vartheta_a \underbrace{A^{1 + \frac{\eta+1/(\alpha-1)}{1-\eta}} \left[\left(\frac{1}{\eta} - 1 \right) \frac{\rho}{\alpha} \right]^{\frac{1}{\alpha-1}}}_{\triangleq \xi_0} . \quad (41)$$

In order to obtain $\dot{\vartheta}_a$, we differentiate this expression with respect to time

$$\dot{\vartheta}_a = \frac{1 - \eta}{\eta + 1/(\alpha - 1)} \left(\frac{\dot{\ell}_a + \chi \ell_a}{\xi_0} \right)^{\frac{1-\eta}{\eta+1/(\alpha-1)}} \frac{\ddot{\ell}_a + \chi \dot{\ell}_a}{\dot{\ell}_a + \chi \ell_a} ,$$

and replace it into (40) to finally derive the law of motion (16) for employment. It obeys a highly non linear second ODE. The employment profile of any given firm can therefore be pinned down using a starting and terminal conditions. First, given that startups have no labor force, we can set $\ell_0 = 0$.⁵² The second condition ensures that employment converges smoothly to its optimal value in the long run, so that both $\dot{\ell}_a$ and $\ddot{\ell}_a$ approach zero as time goes to infinity. Eliminating $\dot{\ell}_a$ and $\ddot{\ell}_a$ from (16), we find that the asymptotic level of employment $\bar{\ell}(z) \triangleq \lim_{a \rightarrow \infty} \ell_a(z)$ is given by the unique solution to (17). Finally the smooth-pasting condition ensures that the labor force schedule is everywhere differentiable, including the employment level $\ell^X(z)$ at which domestic firms start exporting. If the smooth-pasting condition were violated, there would be a kink at $\ell^X(z)$. But this cannot be optimal because adjustment costs are convex, implying that firms could save on recruitment costs by smoothing their convergence path.⁵³

A.2 Derivation of equation (25)

Lemma 1 *For a given value of search W and average productivity \tilde{z} , the equilibrium locus $\theta(z)$ reads*

$$\theta(z) = \left(\frac{\sigma}{\sigma - 1} \frac{W}{A\eta} \right)^{\frac{1}{1-\eta}} \tilde{z}^{-\frac{1}{1-\eta} \frac{\beta}{\sigma-1}} z^{\zeta \frac{\sigma-1}{\sigma}} [1 + \mathbb{I}(z) \tau^{1-\sigma}]^{\frac{\zeta}{\sigma}} , \quad (42)$$

where $\beta > 0$ and $\zeta < 0$ are combinations of parameters defined in (49) and (48).

Equation (5) implies that marginal revenue are proportional to the domestic price which, combined with our normalization, yields

$$R_1(\ell, \mathbb{I}; \tilde{z}) = \frac{\sigma - 1}{\sigma} p_D(\tilde{z}) \tilde{z} = \frac{\sigma - 1}{\sigma} \tilde{z} . \quad (43)$$

Using this identity and the functional forms in Assumptions 1 and 2, one can use the first-order condition $R_1(\ell, \mathbb{I}; z) q'(\theta) = -W/\theta^2$ to solve for the tightness associated to \tilde{z}

$$\tilde{\theta} = \left(\frac{\sigma}{\sigma - 1} \frac{W}{A\eta \tilde{z}} \right)^{\frac{1}{1-\eta}} . \quad (44)$$

⁵²When the revenues function $R(\ell_a, \mathbb{I})$ is isoelastic, as in Melitz's (2003) model, marginal revenues diverge to infinity as ℓ goes to zero. This implies that the ODE (16) admits a singularity at $\ell = 0$. Yet it is well behaved for any arbitrarily small initial size. Hence, in the simulation, we follow Garibaldi and Moen (2010) and circumvent this technical difficulty by assuming that $\ell_0 = \varepsilon$. Letting ε go to zero illustrates that, for sufficiently small ε , the optimal recruitment schedule is not significantly affected by the choice of ε

⁵³Smooth-pasting is a standard optimality condition in firm entry models, explored in details in Dixit and Pindyck (1994) and applied to entry into and exit from the export market in Impullitti, et al. (2013).

Similarly, reinserting our functional forms into equation (24), one obtains a closed form solution for v as a function of θ

$$v(z) = \left(\frac{1-\eta}{\eta\alpha} \frac{W}{\theta(z)} \right)^{\frac{1}{\alpha-1}}. \quad (45)$$

We now explain how posted wages can be derived for all productivity levels. First, note that marginal revenues are related in the following fashion

$$\frac{R_1(\ell, \mathbb{I}; z)}{R_1(\tilde{\ell}, 0; \tilde{z})} = \left(\frac{z}{\tilde{z}} \right)^{\frac{\sigma-1}{\sigma}} [1 + \mathbb{I}(z) \tau^{1-\sigma}]^{1/\sigma} \left(\frac{\tilde{\ell}}{\ell(z)} \right)^{1/\sigma} = \left(\frac{\tilde{\theta}}{\theta(z)} \right)^{1-\eta}. \quad (46)$$

The second equality results from the first order condition $R_1(\ell, \mathbb{I}; z) q'(\theta) = -W/\theta^2$, which—under our parametric assumptions—simplifies to $R_1(\ell, \mathbb{I}; z) = W/(\eta A \theta^{1-\eta})$. Since $\ell = q(\theta)v$, one can solve for the employment levels using equation (45) and substitute them out of equation (46) to obtain

$$\frac{z}{\tilde{z}} = [1 + \mathbb{I}(z) \tau^{1-\sigma}]^{\frac{1}{1-\sigma}} \left(\frac{\theta(z)}{\tilde{\theta}} \right)^{\zeta^{-1} \frac{\sigma}{\sigma-1}}, \quad (47)$$

where

$$\zeta^{-1} \triangleq - \left[1 - \eta + \frac{1}{\sigma} \left(\frac{1}{\alpha-1} + \eta \right) \right] < 0. \quad (48)$$

Tightness is inversely related to productivity as the exponent on the right-hand side of (47) is unambiguously negative. Observe also that the relationship depends on the export status of the firm. If a firm with productivity z decides to export, the indicator function $\mathbb{I}(z)$ switches from zero to one which lowers $\theta(z)$. As expected, everything else equal, the decision to sell on the foreign market leads to an increase in optimal employment. And, to accommodate its expansion, the firm decide to post a higher wage.

The equilibrium tightness is obtained plugging (44) into (47), with

$$\beta \triangleq -\zeta \frac{\sigma-1}{\sigma} \frac{\alpha}{\alpha-1} > 0. \quad (49)$$

The exponents of both z and \tilde{z} in (42) are negative. To derive the exponent of \tilde{z} , one replaces (44) into (47). This yields the expression in (42) but with the following exponent for \tilde{z}

$$- \left(\frac{1}{1-\eta} + \zeta \frac{\sigma-1}{\sigma} \right) = - \frac{1}{1-\eta} \left[1 + \zeta \frac{\sigma-1}{\sigma} (1-\eta) \right] = - \frac{1}{1-\eta} \left[-\zeta \frac{1}{\sigma} \frac{\alpha}{\alpha-1} \right].$$

Replacing the definitions of ζ and of β into the expression above yields the exponent of z and \tilde{z} in (42). Since the exponent of z in (42) is negative, firms with a higher productivity recruit in tighter markets (lower θ) and post higher wages. Furthermore, more productive firms post more vacancies and employ more workers in equilibrium. A higher productivity of the representative firm (\tilde{z}) shifts the $\theta(z)$ locus up, thereby leading to higher wages for all z .

Finally, replacing the results of the Lemma into (22) and taking logarithms,⁵⁴ we obtain the wage profile (25).

A.3 Derivation of equation (26)

Equation (26) is a direct consequence of the Lemma below.

Lemma 2 (Profits) *For given aggregates W and \tilde{z} , operating profits are log-linear in z as*

$$\pi(z; W) + f + \mathbb{I}(z) f_X = K W^{-\frac{\eta}{1-\eta}} \left(\frac{\alpha}{\alpha-1} \right) \tilde{z}^\gamma z^\beta [1 + \mathbb{I}(z) \tau^{1-\sigma}]^{\frac{\beta}{\sigma-1}}, \quad (50)$$

⁵⁴We have made use of $1 + \zeta [(\sigma-1)/\sigma] (1-\eta) = \beta/(\sigma-1)$.

where the constants $K > 0$ and $\gamma > 0$ are defined in (58) and (57). The productivity \tilde{z} of the representative firm is given by

$$\tilde{z} = \left[\frac{1}{1 + \varrho} \int_{z_D^*}^{\infty} z^\beta [1 + \mathbb{I}(z)\tau^{1-\sigma}]^{\frac{\beta}{\sigma-1}} \mu(z) dz \right]^{\frac{1}{\beta}}. \quad (51)$$

The expression for \tilde{z} follows from the normalization of the aggregate price index $P = 1$. Recognizing that $p_X(z) = \tau^{1-\sigma} p_D(z)$ and that the mass of domestically *available* varieties M is related to the mass of domestically *produced* varieties M_D by $M = M_D + \varrho M_D$, since ϱM_D measures the mass of imported varieties, we obtain

$$\begin{aligned} P &= \left[\frac{1}{M} \int_{\omega \in \Omega} p(\omega)^{1-\sigma} d\omega \right]^{\frac{1}{1-\sigma}} = \left[\frac{M_D}{M} \int_{z_D^*}^{\infty} p_D(z)^{1-\sigma} [1 + \mathbb{I}(z)\tau^{1-\sigma}] \mu(z) dz \right]^{\frac{1}{1-\sigma}} \\ &= \left[\frac{1}{1 + \varrho} \int_{z_D^*}^{\infty} p_D(z)^{1-\sigma} [1 + \mathbb{I}(z)\tau^{1-\sigma}] \mu(z) dz \right]^{\frac{1}{1-\sigma}}. \end{aligned}$$

The normalization $P = 1$ implies that

$$1 + \varrho = \int_{z_D^*}^{\infty} p_D(z)^{1-\sigma} [1 + \mathbb{I}(z)\tau^{1-\sigma}] \mu(z) dz. \quad (52)$$

We use (46) to substitute domestic prices out as

$$\frac{R_1(\ell, \mathbb{I}(z); z)}{R_1(\tilde{\ell}, 0; \tilde{z})} = \frac{p_D(z) z}{\tilde{z}} = \left(\frac{\tilde{\theta}}{\theta} \right)^{1-\eta},$$

from which one can make use of equation (47) to express the distribution of producer prices as a function of z

$$p_D(z) = \frac{\tilde{z}}{z} \left(\frac{\tilde{\theta}}{\theta} \right)^{1-\eta} = \left(\frac{\tilde{z}}{z} \right)^{1+\zeta \frac{\sigma-1}{\sigma}(1-\eta)} [1 + \mathbb{I}(z)\tau^{1-\sigma}]^{-\frac{\zeta}{\sigma}(1-\eta)}. \quad (53)$$

Let $\lambda = \zeta [(\sigma - 1)/\sigma](1 - \eta) + 1$, we now show that $\lambda = \beta/(\sigma - 1)$. Using the definition of ζ , note that

$$\lambda = \frac{\alpha}{(\alpha - 1)\sigma \left[\frac{1}{\sigma} \left(\frac{1}{\alpha-1} + \eta \right) + \sigma(1 - \eta) \right]} = -\frac{\zeta}{\sigma} \frac{\alpha}{\alpha - 1} = \frac{\beta}{\sigma - 1}$$

Replacing the exponent of \tilde{z}/z in (53) with $\lambda = \beta/(\sigma - 1)$ and plugging the price equation into (52), we obtain (28).

In order to establish the proportionality of profits, we exploit the fact that demand functions are such that $R(z) = [1 + \mathbb{I}(z)\tau^{1-\sigma}] R_D(z)$ as well as $R_D(z) = (z\ell/\tilde{z}\ell)^{(\sigma-1)/\sigma} R_D(\tilde{z})$. Replacing these two equalities into (23) we obtain

$$\pi(z; W) = [1 + \mathbb{I}(z)\tau^{1-\sigma}] \left[\frac{z\ell_D(z)}{\tilde{z}\ell_D(\tilde{z})} \right]^{\frac{\sigma-1}{\sigma}} \tilde{z}\ell_D(\tilde{z}) - \frac{v(z)}{\theta(z)} W - v(z)^\alpha - f - \mathbb{I}(z) f_X, \quad (54)$$

where we have suppressed the dependence of \mathbb{I} , ℓ_D , v and θ on W and \tilde{z} to avoid notational clutter. Using Lemma 1, it is possible to simplify each components of $\pi(z; W)$. Starting with revenues, we observe that

$$\begin{aligned} \frac{z\ell_D(z)}{\tilde{z}\ell_D(\tilde{z})} &= \frac{z}{\tilde{z}} \left(\frac{1}{1 + \mathbb{I}(z)\tau^{1-\sigma}} \right) \frac{\ell(z)}{\ell(\tilde{z})} = \frac{z}{\tilde{z}} \left(\frac{1}{1 + \mathbb{I}(z)\tau^{1-\sigma}} \right) \left(\frac{\theta}{\tilde{\theta}} \right)^{\frac{1}{1-\alpha}-\eta} \\ &= \left(\frac{z}{\tilde{z}} \right)^{1+\zeta \frac{\sigma-1}{\sigma} [\frac{1}{1-\alpha}-\eta]} \left(\frac{1}{1 + \mathbb{I}(z)\tau^{1-\sigma}} \right)^{1-\zeta \frac{1}{\sigma} [\frac{1}{1-\alpha}-\eta]} . \end{aligned}$$

while

$$\tilde{z}l_D(\tilde{z}) = \tilde{z}A\tilde{\theta}^{\frac{1}{1-\alpha}-\eta} \left(\frac{1-\eta}{c\alpha\eta} W \right)^{\frac{1}{\alpha-1}} = \tilde{z}^{1+\frac{1}{\eta-1}(\frac{1}{1-\alpha}-\eta)} W^{-\frac{\eta}{1-\eta} \frac{\alpha}{\alpha-1}} K_1 ,$$

where

$$K_1 \triangleq \left(\frac{1}{\eta} \right)^{-\frac{\eta}{1-\eta} \frac{\alpha}{\alpha-1}} \left(\frac{\sigma}{A(\sigma-1)} \right)^{\frac{1}{1-\eta}(\frac{1}{1-\alpha}-\eta)} A \left(\frac{1-\eta}{\alpha} \right)^{\frac{1}{\alpha-1}} . \quad (55)$$

We can therefore rewrite revenues as

$$(1 + \mathbb{I}(z)\tau^{1-\sigma}) \left[\frac{z\ell_D(z)}{\tilde{z}\ell_D(\tilde{z})} \right]^{\frac{\sigma-1}{\sigma}} \tilde{z}l_D(\tilde{z}) = K_1 W^{-\frac{\eta}{1-\eta} \frac{\alpha}{\alpha-1}} \tilde{z}^\gamma z^\beta [1 + \mathbb{I}(z)\tau^{1-\sigma}]^{\frac{\beta}{\sigma-1}} ,$$

where

$$\beta = \frac{\sigma-1}{\sigma} \zeta \frac{\alpha}{1-\alpha} = \left(\frac{\sigma-1}{\sigma} \right)^2 \zeta \left(\frac{1}{1-\alpha} - \eta \right) + \frac{\sigma-1}{\sigma} > 0 . \quad (56)$$

The sign of β follows from $\zeta < 0$ and $\alpha > 1$. The exponent of \tilde{z} is

$$\gamma \triangleq \left(\frac{1}{\alpha-1} + \eta \right) \left[\frac{1}{1-\eta} + \left(\frac{\sigma-1}{\sigma} \right)^2 \zeta \right] + \frac{1}{\sigma} = \frac{\alpha}{\alpha-1} \frac{1}{1-\eta} - \beta > 0 . \quad (57)$$

The last equality holds because $((\sigma-1)/\sigma)\zeta(1/(1-\alpha)-\eta) + 1 = (\sigma/(\sigma-1))\beta$. To see that γ is positive, observe that this holds true if $(\sigma/(\sigma-1))(1/(1-\eta)) + \zeta > 0$. Replacing the definition of ζ given in (48) and imposing $\alpha > 1$ shows that the last inequality is indeed satisfied. Focusing now on the wage bill, we obtain

$$\begin{aligned} \frac{v(z)}{\theta(z)} &= \left(\frac{1-\eta}{\alpha\eta} W \right)^{\frac{1}{\alpha-1}} \theta(z)^{\frac{1}{1-\alpha}} = \left(\frac{1-\eta}{\alpha\eta} W \right)^{\frac{1}{\alpha-1}} \left[\left(\frac{z}{\tilde{z}} (1 + \mathbb{I}(z)\tau^{1-\sigma})^{\frac{1}{\sigma-1}} \right)^{\zeta \frac{\sigma-1}{\sigma}} \tilde{\theta} \right]^{\frac{\alpha}{1-\alpha}} \\ &= \left(\frac{1-\eta}{\alpha\eta} W \right)^{\frac{1}{\alpha-1}} \tilde{z}^\gamma z^\beta (1 + \mathbb{I}(z)\tau^{1-\sigma})^{\frac{\beta}{\sigma-1}} . \end{aligned}$$

Finally, turning our attention to the expression for recruitment costs, we find that

$$v(z)^\alpha = \left(\frac{1-\eta}{c\alpha\eta} W \right)^{\frac{\alpha}{\alpha-1}} \theta(z)^{\frac{\alpha}{1-\alpha}} = \left(\frac{1-\eta}{c\alpha\eta} W \right)^{\frac{\alpha}{\alpha-1}} \tilde{\theta}^{\frac{\alpha}{1-\alpha}} \left(\frac{z}{\tilde{z}} \right)^{\zeta \frac{\sigma-1}{\sigma} \frac{\alpha}{1-\alpha}} (1 + \mathbb{I}(z)\tau^{1-\sigma})^{\zeta \frac{1}{\sigma} \frac{\alpha}{1-\alpha}} .$$

Hence, adding all the terms above yields

$$\pi(z; \tilde{z}, W) = KW^{-\frac{\eta}{1-\eta}(\frac{\alpha}{\alpha-1})} \tilde{z}^\gamma z^\beta [1 + \mathbb{I}(z; W, \tilde{z})\tau^{1-\sigma}]^{\frac{\beta}{\sigma-1}} - f - \mathbb{I}(z; W, \tilde{z})f_X .$$

The constant K reads

$$K \triangleq K_1 - \left[\left(\frac{1-\eta}{\alpha\eta} \right)^{\frac{1}{\alpha-1}} + \left(\frac{1-\eta}{\alpha\eta} \right)^{\frac{\alpha}{\alpha-1}} \right] \left(A\eta \frac{\sigma-1}{\sigma} \right)^{-\frac{1}{1-\eta} \frac{\alpha}{\alpha-1}} , \quad (58)$$

where K_1 is defined in equation (55).

A.4 Derivation of the free entry condition (30)

The free entry condition ensures that entry occurs until expected profits are exactly identical to the entry costs f_E , hence

$$E[\pi(z)] = \frac{f_E}{1 - G(z_D^*)}. \quad (59)$$

The expectation operator $E[\cdot]$ aggregates over levels of z that are consistent with positive profits, i.e.,

$$E[\pi(z)] = \frac{\int_{z_D^*}^{\infty} \pi(z) dG(z)}{1 - G(z_D^*)} = \int_{z_D^*}^{\infty} \pi(z) \mu(z) dz. \quad (60)$$

In order to use condition (59), we need to relate expected profits $E[\pi(z)]$ to the profits $\tilde{\pi}$ of the representative firm. The definition in (60) and the proportionality of profits established in Lemma 2 ensure that

$$E[\pi(z)] + f + \varrho f_X = [\tilde{\pi} + f] \int_{z_D^*}^{\infty} \left(\frac{z}{\tilde{z}}\right)^\beta [1 + \mathbb{I}(z)\tau^{1-\sigma}]^{\frac{\beta}{\sigma-1}} \mu(z) dz.$$

But we know from the definition of \tilde{z} in (28) that the integral on the right hand side is equal to $1 + \varrho$, which implies in turn that

$$E[\pi(z)] + f + \varrho f_X = [\tilde{\pi} + f] (1 + \varrho). \quad (61)$$

Equation (61) provides us with the desired mapping between expected profits $E[\pi(z)]$ and $\tilde{\pi}$. Accordingly, we can substitute $\tilde{\pi}$ out of (59) to obtain the free entry condition

$$(FE) : \tilde{\pi} = \frac{1}{1 + \varrho} \left[\frac{f_E}{1 - G(z_D^*)} + \varrho(f_X - f) \right]. \quad (62)$$

Using the definition of ϱ , expression (30) follows.

A.5 Proof of Proposition 3

Derivative of \tilde{z} with respect to z_D^* . Denote $\partial z_X^* / \partial z_D^* \equiv k$, where we know $k > 1$ from (29). We rewrite expression (28) as

$$\begin{aligned} \tilde{z}^\beta &= \frac{1}{2 - G(z_D^*) - G(z_X^*)} \int_{z_D^*}^{\infty} z^\beta [1 + \mathbb{I}(z)\tau^{1-\sigma}]^{\beta/(\sigma-1)} g(z) dz \\ \frac{\partial \tilde{z}^\beta}{\partial z_D^*} &= \frac{g(z_D^*) + g(z_X^*)k}{[2 - G(z_D^*) - G(z_X^*)]^2} \int_{z_D^*}^{\infty} z^\beta [1 + \mathbb{I}(z)\tau^{1-\sigma}]^{\beta/(\sigma-1)} g(z) dz \\ &\quad - \frac{1}{2 - G(z_D^*) - G(z_X^*)} z_D^{*\beta} g(z_D^*) \\ \frac{\partial \tilde{z}^\beta}{\partial z_D^*} \frac{z_D^*}{\tilde{z}^\beta} &= \frac{g(z_D^*) z_D^*}{2 - G(z_D^*) - G(z_X^*)} \left[1 + \frac{g(z_X^*)}{g(z_D^*)} k - \left(\frac{z_D^*}{\tilde{z}}\right)^\beta \right] \\ &\simeq \frac{G(z_D^*)}{2 - G(z_D^*) - G(z_X^*)} \left[1 + \frac{g(z_X^*)}{g(z_D^*)} k - \left(\frac{z_D^*}{\tilde{z}}\right)^\beta \right] \\ \frac{\partial \tilde{z}^\beta}{\partial z_D^*} \frac{z_D^*}{\tilde{z}^\beta} &> 0 \iff \left(1 + \frac{g(z_X^*)}{g(z_D^*)} k \right) \left(\frac{\tilde{z}}{z_D^*}\right)^\beta > 1 \end{aligned}$$

which is always true since the representative firm has higher productivity than the marginal producer, $\tilde{z} > z_D^*$, and $\frac{\partial z_X^*}{\partial z_D^*} > 1$. For the same initial z_D^* , an increase of z_D^* has a stronger effect on \tilde{z} in our model

than in the Melitz model (where β is replaced by $\sigma - 1$).
Also note that

$$\frac{\partial \tilde{z}^\beta}{\partial \tau} \frac{\tau}{\tilde{z}^\beta} = -\beta \frac{\tau^{1-\sigma}}{1 + \tau^{1-\sigma}} \iff \frac{\partial \tilde{z}}{\partial \tau} \frac{\tau}{\tilde{z}} = -\frac{\tau^{1-\sigma}}{1 + \tau^{1-\sigma}}.$$

Slope of free entry condition. We have

$$\frac{\partial \tilde{\pi}}{\partial z_D^*} = \frac{-g(z_X^*) (f_X - f) k [2 - G(z_D^*) - G(z_X^*)] + [f_E + [1 - G(z_X^*)] (f_X - f)] [g(z_D^*) + g(z_X^*) k]}{[2 - G(z_D^*) - G(z_X^*)]^2}.$$

Then, $\partial \tilde{\pi} / \partial z_D^* > 0$ is equivalent to

$$[f_E + [1 - G(z_X^*)] (f_X - f)] [g(z_D^*) + g(z_X^*) k] > g(z_X^*) (f_X - f) k [2 - G(z_D^*) - G(z_X^*)],$$

or

$$\frac{\tilde{\pi}}{[(f_X - f) - \tilde{\pi}]} > \frac{g(z_X^*)}{g(z_D^*)} k.$$

Using the expression for $\tilde{\pi}$ from (30), one can show that, under the sufficient condition $f_X < f_E$,

$$\begin{aligned} (f_X - f) - \tilde{\pi} &= (f_X - f) - \frac{f_E + [1 - G(z_X^*)] (f_X - f)}{2 - G(z_D^*) - G(z_X^*)} < 0 \\ \iff f_X &< \frac{f_E + [1 - G(z_X^*)] (f_X - f)}{2 - G(z_D^*) - G(z_X^*)} + f = \frac{f_E + [1 - G(z_X^*)] f_X + [1 - G(z_D^*)] f}{2 - G(z_D^*) - G(z_X^*)}. \end{aligned}$$

The condition is equivalent to

$$f_X < \frac{f_E}{1 - G(z_D^*)} + f,$$

which always holds if $f_X < f_E$. Moreover,

$$\left. \frac{\partial \tilde{\pi}}{\partial z_D^*} \frac{z_D^*}{\tilde{\pi}} \right|_{FE} = \frac{[g(z_D^*) + g(z_X^*) k] z_D^*}{2 - G(z_D^*) - G(z_X^*)}.$$

Slope of zero cutoff profit condition. The ZCP is identical to the one derived by Melitz (2003) for the case of a closed economy. Totally differentiating with respect to z_D^* , one obtains

$$\begin{aligned} \left. \frac{\partial \tilde{\pi}}{\partial z_D^*} \frac{z_D^*}{\tilde{\pi}} \right|_{ZPC} &= -\frac{\beta}{1 - (z_D^*/\tilde{z})^\beta} \left(1 - \frac{\partial \tilde{z}}{\partial z_D^*} \frac{z_D^*}{\tilde{z}} \right) \\ &= -\frac{1}{1 - (z_D^*/\tilde{z})^\beta} \left(\beta - \frac{g(z_D^*) z_D^*}{2 - G(z_D^*) - G(z_X^*)} \left[1 - (z_D^*/\tilde{z})^\beta + \frac{g(z_X^*) k}{g(z_D^*)} \right] \right). \end{aligned}$$

Melitz (2003) shows that for standard families of distribution functions, this expression is non-positive. For given z_D^* , we obtain

$$\left. \frac{\partial \tilde{\pi}}{\partial \tilde{z}} \frac{\tilde{z}}{\tilde{\pi}} \right|_{ZPC} = \frac{\beta}{1 - (z_D^*/\tilde{z})^\beta},$$

which is positive when $\beta > 1$ since $1 - (z_D^*/\tilde{z})^\beta > 0$. In terms of fundamental parameters, the restriction $\beta > 1$ is met if $\sigma > 1 + \alpha$. To see this, we employ the definition of β

$$\beta = \frac{(\sigma - 1) \alpha}{(\alpha - 1) [(1 - \eta) \sigma + \eta] + 1}.$$

It is easy to show that $\beta > 1 \iff [1 + \eta(\alpha - 1)](\sigma - 1) > \alpha$. Since $1 + \eta(\alpha - 1) > 1$, we have $\sigma > 1 + \alpha \implies \beta > 1$.

A.6 Derivation of equation (33)

The aggregate level of employment is by definition equal to

$$L = M_D \int_{z_D^*}^{\infty} \ell(z) \mu(z) dz = M_D A \left(\frac{1-\eta}{\alpha\eta} W \right)^{\frac{1}{\alpha-1}} \int_{z_D^*}^{\infty} \theta(z)^{-(\eta+\frac{1}{\alpha-1})} \mu(z) dz . \quad (63)$$

To simplify this expression, we have to derive the mass of domestic firms M_D . Given that a firm with productivity z recruits his workers from a pool of unemployed workers with mass $s(z) = \ell(z) / [\theta(z) q(\theta(z))]$, integrating over all levels of productivity yields

$$S = M_D \int_{z_D^*}^{\infty} \left[\frac{\ell(z)}{\theta(z) q(\theta(z))} \right] \mu(z) dz = M_D \left(\frac{1-\eta}{\alpha\eta} W \right)^{\frac{1}{\alpha-1}} \int_{z_D^*}^{\infty} \theta(z)^{\frac{1}{1-\alpha}} \mu(z) dz , \quad (64)$$

where S is the mass of job seekers. Lemma 1 allows us to simplify the integral

$$\begin{aligned} \int_{z_D^*}^{\infty} \theta(z)^{\frac{1}{1-\alpha}} d\mu(z) &= \int_{z_D^*}^{\infty} \left[\tilde{\theta} \left(\frac{z}{\bar{z}} \right)^{\zeta \frac{\sigma-1}{\sigma}} [1 + \mathbb{I}(z) \tau^{1-\sigma}]^{\frac{\zeta}{\sigma}} \right]^{\frac{1}{1-\alpha}} \mu(z) dz \\ &= \tilde{\theta}^{\frac{1}{1-\alpha}} \int_{z_D^*}^{\infty} \left(\frac{z}{\bar{z}} \right)^{\beta} [1 + \mathbb{I}(z) \tau^{1-\sigma}]^{\frac{\beta}{\sigma-1}} \mu(z) dz . \end{aligned}$$

But we know from (28) that the integral on the right hand side equals $1 + \varrho$, which implies in turn that

$$\int_{z_D^*}^{\infty} \theta(z)^{\frac{1}{1-\alpha}} \mu(z) dz = \tilde{\theta}^{\frac{1}{1-\alpha}} (1 + \varrho) .$$

Reinserting this equality into (64) and setting $S = 1$, we find that

$$M_D = \left(\frac{1-\eta}{\alpha\eta} W \right)^{\frac{1}{1-\alpha}} \frac{\tilde{\theta}^{\frac{\alpha}{\alpha-1}}}{1 + \varrho} .$$

Substituting M_D in (63), we finally get

$$L = \frac{A}{1 + \varrho} \tilde{\theta}^{\frac{\alpha}{\alpha-1}} \int_{z_D^*}^{\infty} \theta(z)^{-(\eta+\frac{1}{\alpha-1})} \mu(z) dz ,$$

Finally, Lemma 1 allows us to substitute out the vacancy-unemployment ratios

$$L = A \tilde{\theta}^{1-\eta} \frac{\int_{z_D^*}^{\infty} z^{-(\eta+\frac{1}{\alpha-1})\zeta \frac{\sigma-1}{\sigma}} [1 + \mathbb{I}(z) \tau^{1-\sigma}]^{-\frac{\zeta}{\sigma}(\eta+\frac{1}{\alpha-1})} \mu(z) dz}{(1 + \varrho) \tilde{z}^{-(\eta+\frac{1}{\alpha-1})\zeta \frac{\sigma-1}{\sigma}}} .$$

The exponents can be simplified using the definition of β in (56) to obtain (33) with \bar{z} being given by

$$\bar{z} \triangleq \left[\frac{1}{1 + \varrho} \int_{z_D^*}^{\infty} z^{\beta \frac{\sigma}{\sigma-1} - 1} [1 + \mathbb{I}(z) \tau^{1-\sigma}]^{\frac{1}{\sigma-1} (\beta \frac{\sigma}{\sigma-1} - 1)} \mu(z) dz \right]^{\frac{1}{\beta \frac{\sigma}{\sigma-1} - 1}} . \quad (65)$$

A.7 Wage distribution when $G(z)$ is Pareto

Let $\mu_X(z)$ and $\mu_D(z)$ denote the distribution of productivity among exporters and domestic producers, respectively. When $G(z)$ is Pareto we have by definition

$$\mu_X(z) = \frac{g(z)}{1 - G(z_X)} = \kappa z_X^{*\kappa} z^{-\kappa-1}, \text{ and } \mu_D(z) = \frac{g(z)}{G(z_X) - G(z_D)} = \frac{\kappa z_D^{*\kappa} z^{-\kappa-1}}{1 - \left(\frac{z_D^*}{z_X^*}\right)^\kappa}.$$

The distribution of wages follows weighting the density above by firm sizes. Starting with exporters, one obtains

$$g_X^w(z) = \frac{\int_{z_X^*}^{z(w)} \ell(x) \mu_X(x) dx}{\int_{z_X^*}^{\infty} \ell(x) \mu_X(x) dx} = \frac{\int_{z_X^*}^{z(w)} x^{\beta \frac{\alpha-1}{\alpha} (\eta + \frac{1}{\alpha-1}) - \kappa - 1} dx}{\int_{z_X^*}^{\infty} x^{\beta \frac{\alpha-1}{\alpha} - \kappa - 1} dx} = 1 - \left(\frac{z(w)}{z_X^*}\right)^{\beta \frac{\alpha-1}{\alpha} (\eta + \frac{1}{\alpha-1}) - \kappa},$$

where, with some slight abuse of notation, $z(w)$ is the inverse function for $w(z)$. To write the previous expression in terms of wages, we use the proportionality relationship

$$\frac{w(z)}{w(z_X^*)} = \left(\frac{z}{z_X^*}\right)^{1 - \frac{\beta}{\sigma-1}} \Rightarrow \frac{z(w)}{z_X^*} = \left(\frac{w}{w(z_X^*)}\right)^{\frac{\sigma-1}{\sigma-1-\beta}}.$$

Reinserting this identity in the previous equation yields a Pareto distribution with shape parameter $\kappa_w = (\sigma - 1) [\kappa - \beta \alpha^{-1} (\alpha - 1) (\eta + 1/(\alpha - 1))] / (\sigma - 1 - \beta)$. The wage distribution among domestic producers can be derived in a similar fashion. Skipping intermediate steps, one gets

$$g_D(z) = \frac{\int_{z_D^*}^z \ell(x) \mu_D(x) dx}{\int_{z_D^*}^{z_X^*} \ell(x) \mu_D(x) dx} = \frac{1 - \left(\frac{z}{z_D^*}\right)^{\beta \frac{\alpha-1}{\alpha} (\eta + \frac{1}{\alpha-1}) - \kappa}}{1 - \left(\frac{z_X^*}{z_D^*}\right)^{\beta \frac{\alpha-1}{\alpha} (\eta + \frac{1}{\alpha-1}) - \kappa}}.$$

Once productivity z have been replaced by wages, $g_D^w(w)$ becomes equivalent to a truncated Pareto distribution with shape parameter κ_w .

A.8 Proof of Proposition 4

We start by showing that the FE condition shifts down with $\Delta\tau < 0$. To see this, note that $\partial z_X^* / \partial \tau|_{z_D^* = const.} > 0$, and differentiate the FE condition with respect to τ for given z_D^* ,

$$\frac{\partial \tilde{\pi}_{FE}}{\partial \tau} = \frac{-(f_X - f) g(z_X^*) \frac{\partial z_X^*}{\partial \tau} [2 - G(z_D^*) - G(z_X^*)] + \{f_E + [1 - G(z_X^*)] (f_X - f)\} g(z_X^*) \frac{\partial z_X^*}{\partial \tau}}{\{2 - G(z_D^*) - G[z_X^*(z_D^*)]\}^2},$$

where all derivatives are understood as relating to fixed z_D^* . This implies

$$\frac{\partial \tilde{\pi}_{FE}}{\partial \tau} > 0 \Leftrightarrow \{f_E - (f_X - f) [1 - G(z_D^*)]\} g(z_X^*) \frac{z_X^*}{\partial \tau} > 0 \Leftrightarrow \{f_E - (f_X - f) [1 - G(z_D^*)]\} > 0.$$

The last inequality is satisfied under the sufficient condition $f_E > f_X$, which has been employed in proof of Proposition 3. Bringing the ZCP condition into the picture, product market equilibrium $\pi(\tilde{z})_{ZPC} = \pi(\tilde{z})_{FE}$ is characterized by

$$f \left[\left(\frac{\tilde{z}(z_D^*)}{z_D^*} \right)^\beta - 1 \right] = \frac{f_E + \{1 - G[z_X^*(z_D^*)]\} (f_X - f)}{2 - G(z_D^*) - G[z_X^*(z_D^*)]}.$$

Totally differentiating the equilibrium condition and using the notation $\hat{x} = dx/x$, we obtain

$$-\left[\frac{\beta}{1 - (z_D^*/\tilde{z})^\beta} + \frac{[g(z_D^*) + g(kz_D^*)k]z_D^*}{2 - G(z_D^*) - G(z_X^*)} \right] \hat{z}_D^* = \frac{\beta}{1 - (z_D^*/\tilde{z})^\beta} \frac{\tau^{1-\sigma}}{1 + \tau^{1-\sigma}} \hat{\tau}.$$

We have already shown in the proof of Proposition 3 that z_D^* is decreasing in τ when $\beta > 1$. So, if the sufficient condition $\beta > 1$ holds, $\hat{z}_D^*/\hat{\tau} < 0$ and trade liberalization (lower τ) indeed increases z_D^* . We still have to prove that \tilde{z} is increasing in z_D^* . Reinserting the Pareto distribution into the definition of \tilde{z} , we obtain

$$\begin{aligned} \tilde{z}^\beta &= \frac{1}{1 + \varrho} \int_{z_D^*}^{\infty} z^\beta [1 + \mathbb{I}(z) \tau^{1-\sigma}]^{\frac{\beta}{\sigma-1}} \kappa z_D^{*\kappa} z^{-\kappa-1} dz \\ &= \frac{z_D^{*\kappa}}{1 + \varrho} \frac{\kappa}{\kappa - \beta} \left[z_X^{*\beta-\kappa} \left([1 + \tau^{1-\sigma}]^{\frac{\beta}{\sigma-1}} - 1 \right) + z_D^{*\beta-\kappa} \right]. \end{aligned}$$

But we know from equation (29) that

$$[1 + \tau^{1-\sigma}]^{\frac{\beta}{\sigma-1}} - 1 = \frac{f_X}{f} \left(\frac{z_D^*}{z_X^*} \right)^\beta,$$

while the share of exporters $\varrho = (z_D^*/z_X^*)^\kappa$. We can therefore rewrite the equality above as

$$\tilde{z}^\beta = \frac{\kappa}{\kappa - \beta} z_D^{*\beta} \left[\frac{1 + \varrho \left(\frac{f_X}{f} \right)}{1 + \varrho} \right].$$

Given that ϱ is increasing in z_D^* , we indeed have \tilde{z} increasing in z_D^* whenever $f_X > f$.

A.9 Aggregate employment L when $G(z)$ is Pareto

With the Pareto assumption, equation (33) can be stated as $L = \tilde{\theta} q(\tilde{\theta}) \Lambda$ where

$$\Lambda = \left(\frac{[1 + \tau^{1-\sigma}]^{\frac{\beta}{\sigma-1}} \kappa}{2} \right)^{\frac{1}{\beta} - \frac{1}{\sigma-1}} \frac{[\kappa - \beta]^{\frac{\sigma}{\sigma-1} - \frac{1}{\beta}}}{\kappa - \beta \frac{\sigma}{\sigma-1} + 1}.$$

To understand the mapping between \tilde{z} and $\tilde{\theta}$, it is helpful to combine the expressions of $\tilde{\theta}$ in (42) and of W in (31) to obtain

$$\tilde{\theta} q(\tilde{\theta}) = \tilde{\theta}^{1-\eta} = \frac{\sigma}{\sigma-1} \frac{W}{A\eta\tilde{z}} = \frac{\sigma}{(\sigma-1)A\eta} \left[\frac{K}{f} \left(\frac{z_D^*}{\tilde{z}} \right)^\beta \right]^{\frac{1-\eta}{\eta} \frac{\alpha-1}{\alpha}} \tilde{z}^{\frac{1}{\eta}-1}.$$

When $G(z)$ is Pareto and all firms export, the ratio (z_D^*/\tilde{z}) is constant. Hence the elasticity of $\tilde{\theta}$ with respect to \tilde{z} is also constant and equal to $1/\eta > 0$.

B Data Appendix

B.1 The SIAB data base (Figure 2)

The Sample of Integrated Labour Market Biographies (Stichprobe der integrierten Arbeitsmarktbiographien - SIAB) is a 2% sample of the population of the Integrated Employment Biographies (IEB) of the Institute for Employment Research (Institut für Arbeitsmarktund Berufsforschung - IAB).⁵⁵ The IEB comprises all workers in Germany subject to social security. The major excluded groups are civil servants and self-employed. The data is process-produced from administrative sources such as the notification process by which firms are legally obliged to register workers to the Federal Employment Agency and report any changes in wage or employment structure. The current version of the SIAB contains employment histories of 1,659,024 individuals, documented in 40,501,525 data records. The SIAB comprises data reaching as far back as 1975, and it is organized by spells (worker-plant matches).

Amongst other things, the data provides unique identifiers for persons and establishments (which allows the computation of plant fixed-effects), information about the gross daily pay, the occupation of the worker, socio-demographic characteristics such as year of birth, sex, citizenship, school education, and so on, basic characteristics of the employing establishment such as industry code (five digit), number of (full) employees and median gross daily pay, and so on.

Generally, the data comprised in the SIAB can be considered to be very reliable. This is particularly true for information collected not exclusively for statistical purposes: for instance, the data on remuneration are used by the German Statutory Pension Insurance to calculate pension claims. The educational variable is less reliable because an incorrect information there neither hurts the employer nor the employee. However, well-established procedures are available to cleanse the education variable to make it more accurate (Fitzenberger et al., 2006). Additional issues arise with regard to the industry classification which has changed several times; but industry classifications can be harmonized following the proposal of Card et al. (2013) at the two-digit level.

Finally, a very important issue with the data relates to the top-coding of the wage variable. Daily wages are right-censored at the maximum level on which Social Security contributions are based. Following Dustmann et al. (2009) and Card et al. (2013), we use Tobit regressions to impute wages above the cut-off level. For each year we run a separate regression using age, age squared, tenure, tenure squared, gender, foreign nationality as well as a full set of industry dummies. Missing wages are replaced by predicted values from the Tobit model.

B.2 The LIAB data base (Figure 3)

The LIAB data base is a linked employer-employee data base provided by the Institute of Labor market Research (IAB).⁵⁶ Its core is the so called IAB establishment panel, which provides plant-level information. Based on a unique establishment identifier, the IAB merges the information of the universe of socially secured employees at the plant level to the establishment data. The establishment panel is a yearly survey which includes establishments with at least one employee covered by social security. The sample is drawn following the principle of optimum stratification. These stratification cells are also used in the weighting and extrapolation of the sample. The survey is conducted by interviewers from TNS Infratest Sozialforschung. About 4300 establishments from Western Germany participate in the survey. The response rate of units that have been interviewed repeatedly is over 80%. We use the cross-sectional version of the data set for the years 1996 to 2007.

One problem with the plant-level data is its lack of representativeness. However, the IAB represents sampling weights which can be employed to reconstruct a representative sample of German plants. The plant-level information is very rich; it covers details about the plants' industrial relations, information about the structure of its work-force, and, quite important for our purposes, on total revenue and on the export share of the plant. It has information on the total wage bill and on the age of the establishment, as well as on establishment size and industry.

⁵⁵A comprehensive introduction to the SIAB data set is provided by Dorner et al. (2010).

⁵⁶A comprehensive introduction to the LIAB data set is provided by Alda et al. (2005).

B.3 Aggregate data (Table 3)

We report a measure of residual inequality that is attributable to establishment effects. We obtain this information by multiplying the standard deviation of log raw wages by the share of variance explained by establishment effects as estimated by Card et al. (2013). Raw inequality is 0.40 log points in 1996, while the share of total wage variation in 1996 is 0.205. In 2007 the estimates are 0.526 and 0.21, respectively.

The trade openness measure is based on a value added metric rather than on the usual ratio of gross trade over GDP. In the presence of an internationally fragmented value chain, gross exports (the value of exports at the border as declared to customs) overestimates the value added content of domestic production aimed for foreign consumption. The reason is that export of some country increasingly include foreign inputs. Similarly, a country's imports may include a non-trivial measure of its own value added. To compute the domestic value added content of exports and the foreign value added content of imports, one requires a matrix of input-output tables for the entire world. the World Input-Output Data (WIOD) consortium has produced such matrices for the years 1995 to 2009; it is available under www.wiod.org. Details of calculations are provided by Aichele et al. (2013).

In Germany, the outsourcing trend has been strong over the last 15 years. From 1995 to 2007, the VAX ratio (value added exports divided by gross exports) has fallen from 74 to 66%. A similar trend is observable for imports. Hence, adjusting gross data for their value added content leads to a sizeable reduction of the measured openness. Nonetheless, it remains true that openness has increased very strongly from 1996 to 2007 in Germany.

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