Wages, productivity, and market power*

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October 24, 2014

Abstract

We explore relationships between wages, productivity and market power within a framework that captures labor market rigidities, firm heterogeneity, and variable markups. Productivity is only one of the factors that potentially can explain variation of wages within an industry. Another important determinant of wages can be the firm's market power. More precisely, the outcome of the bargaining game between a firm and its workers depends crucially on the demand side characteristics. Hence, firm's markup also may serve as a good explanatory variable for the wage rate set by the firm. We provide a micro foundation for this channel of wage determination.

We test our predictions using Ukrainian firm-level data. An increase in productivity weakly increases an average wage within a firm, but the effect is small and not robust. The elasticity of wage with respect to labor productivity is 0.064 in the baseline specification, but the coefficient is not statistically significant. An increase in the markup also results in an increase in the average wage. The effect is almost three times higher, statistically significant, and is robust to various model specifications. The positive sign of the markup coefficient indicates that the elasticity of aggregate demand is decreasing function of output. Based on the industry-level analysis, we find evidence supporting the bell-shaped relationship between the coefficient of variation of wages and the share of exporting firms in the industry.

Keywords: Wage bargaining; wage inequality; heterogeneous firms; productivity; variable markups; international trade; monopolistic competition

JEL Classification: D43, F12, J31

*We thank C. d'Aspremont, K. Behrens, R. Dos Santos, D. Levando, M. Parenti and J.-F. Thisse for valuable suggestions. The financial support from the Government of the Russian Federation under the grant 11.G34.31.0059 is acknowledged.

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1 Introduction

Rising wage inequality **across countries** over the last 20 years, which according to OECD (2012) was the main contributor to the rising household income inequality in both rich and poor countries, is often linked to globalization. According to Goldberg and Pavcnik (2007), trade liberalization in Chile in 70's, in Mexico in 80's, in Argentina, Colombia, and India in 90's came along with the increasing wage inequality. The traditional Heckscher-Ohlin model fails to explain an increasing wage gap between skilled and unskilled labor that occurred both in rich and poor countries over the last two decades. In addition, it cannot account for a large variation in wages within a narrowly defined industry reported in the literature (Dunne et al., 2004). Recently, Helpman et al. (2010, hereafter HIR) (and some others authors, including (Egger and Kreickemeier, 2012; Felbermayr et al., 2011; Amiti and Davis, 2012) suggested a new class of models that link changes in wage inequality to the distributional changes in productivity within an industry. In their framework, heterogeneous firms, facing a labor market with search and matching frictions, in equilibrium pay wages that increase with productivity. Wage inequality within an industry in these models is driven by technological differences acorss firms.

However, these models are based on identical constant elasticity of substitution (CES) preferences across consumers, which precludes any effect of trade liberalization on firm's market power. More precisely, because CES preferences generate an isoelastic market demand, the equilibrium markups are constant. This prediction does not seem realistic – substantial variation of markups across firms is well-documented (De Loecker and Warzynski, 2012). Moreover, the variation in market power across firms has an important impact on their performance (Syverson, 2004; Foster et al., 2008). In particular, it can influence firm's wage decision, which is determined in a bargaining game over the firm's profit.

The link between wages and markups has been extensively studied in recent macroeconomics literature (i.e. Nakamura and Zerom, 2010). However, to the best of our knowledge, there are no studies of this link from the international trade perspective. This paper aims to fill this gap in the literature. **More concretely,** we explore relationships of wages, productivity and market power within a framework that captures labor market rigidities, firm heterogeneity, and variable markups. **For this purpose,** we combine approaches of HIR and Zhelobodko et al. (2012, hereafter ZKPT). HIR explains variation in wages as a result of exogenous variation in productivity. However, productivity is only one of the factors that potentially can explain variation in wages. Another important determinant of wages can be the firm's markup. To be precise, bargaining game between workers and the firm is about splitting the revenue, which depends on the market power. We provide a micro foundation for this channel, which stems from the fact that the outcome of the bargaining game crucially depends on the demand side characteristics.

Our main results may be summarized as follows. First, we derive the wage-productivity equation, which **describes the link between firm-level productivities, markups, and wages. This equation says that more productive firms charge higher wages. Moreover, firms with higher market power charge higher (lower) wages if and only if the aggregate demand elasticity is a decreasing (increasing) function of output.

Second, we estimate the log-linearized version of the wage-productivity equation, focusing mainly on the sign of the markup coefficient, because the elasticity of wage with respect to the markup summarizes all the relevant features of the demand structure of the model.

Third, to cope with endogeneity of markups, we use the result that markups of exporting firms depend on trade costs and demand charactristics of importing countries. We also exploit the regulatory changes in trade policy to generate an exogenous variation in firms' productivity in order to solve an omitted variable bias, which arises due to unobserved workers' abilities.

In addition, an increase in productivity leads to an increase in the average wage per worker, but the result is economically small and not robust. The elasticity of wage with respect to productivity is 0.064 in the baseline specification. An increase in the markup also results in the increase in the average wage, but the effect is three times higher and is robust to various model specifications. The positive sign of the markup coefficient indicates that the elasticity of aggregate demand is decreasing function of output.

Finally, based on the industry-level analysis, we find evidence supporting the bell-shaped relationship between the coefficient of variation of wages and the share of exporting firms in the industry. Finally, we propose a method of estimating superelasticity of aggregate demand, which is different from the one suggested by Nakamura and Zerom (2010).

The rest of the paper proceeds as follows. Section 2 develops a theoretical model and derives the wage-productivity equation. Section 3 describes the data. Section 4 outlines the identification strategy. Section 5 presents results. Section 6 concludes.

2 Model

In this section we describe our theoretical framework that combines features of HIR and ZKPT. As in Helpman et al. (2010), we consider a two-country model with costly trade. Markets are monpolistically-competitive, which means that each firm is non-atomic. Firms are heterogeneous in productivity and workers are heterogeneous in ability. Labor market has two sources of imperfections. First, firms do not directly observe workers' abilities, hence they bear screening costs. Second, the search process for job candidates is costly. Unlike HIR, we do not impose any parametric specifications of preferences. Instead, in the spirit of ZKPT, we assume non-specified additive preferences, which implies that firms face non-isoelastic demands on both home and foreign markets. In addition, we do not restrict the model to a specific parametrization of the distribution of abilities. Our model is described as follows.

2.1 Consumers

Each of the two countries is populated by a unit mass of consumers. Consumers share the same additive preferences given by

$$\mathcal{U} \equiv \int_0^N u(q_i)\mathrm{d}i + \int_0^{N^*} u(q_j^*)\mathrm{d}j \tag{1}$$

where q_i is consumption of domestic variety i and q_j^* is consumption of foreign variety j. Each consumer maximizes (1) subject to the budget constraint

$$\int_0^N p_i q_i \mathrm{d}i + \int_0^{N^*} p_j^* q_j^* \mathrm{d}j \le w \tag{2}$$

The individual inverse demand for variety i is given by

$$p_i = \frac{u'(q_i)}{\lambda} \tag{3}$$

where λ is the Lagrange multiplier **of the program (1) – (2),** which shows marginal utility of income.

It is worth noting that consumers are heterogeneous in income, because workers with different levels of ability may earn different wages. As a consequence, the values of λ may also vary across consumers. We denote $\mathbf{\Lambda}$ and $\mathbf{\Lambda}^*$as the distribution of λ's at home and foreign countries respectively.

2.2 Firms

Each country accommodates a continuum of firms. As mentioned, we assume that firms are non-atomic, which means that the impact of firm's behavior on market aggregates is negligible. **In other words, unlike oligopoly models, here firms are not involved into strategic interactions. However, they are involved into *weak interactions*, which occur through the impact of collective firms' behavior on the market aggregates.** Firms are heterogeneous in overall productivity θ drawn from a distribution $\Gamma(\theta)$, **which is** common for both countries. Each firm produces at most one variety, and each variety is produced by at most one firm. In other words, there are no scope economies.

Equation (3) implies that the aggregate demand faced by domestic firm i at the domestic market is given by

$$y_i = D(p_i; \mathbf{\Lambda}) \equiv \int_0^\infty (u')^{-1} (\lambda p_i)\mathrm{d}\mathbf{\Lambda}(\lambda) \tag{4}$$

It follows from (4) that if a firm chooses to sell y_d units of its product at the home market, then it receives revenue

$$R(y_d; \mathbf{\Lambda}) \equiv y_d \Delta(y_d; \mathbf{\Lambda}), \tag{5}$$

where $\Delta(y; \mathbf{\Lambda}) = D^{-1}(y; \mathbf{\Lambda})$ is the inverse aggregate demand. Similarly, selling y_x units at the foreign market yields revenue $R(y_x/\tau; \mathbf{\Lambda}^*)$, where τ is the iceberg transportation cost.

To export or not to export?

Consider exporting behavior of a firm. We assume that if a firm chooses to export it faces fixed cost of exporting $f_e > 0$. Firm's total revenue $\mathcal{R}$ as a function of its total output y is given by

$$\mathcal{R}(y) \equiv (1 - I_x) R(y; \mathbf{\Lambda}) + I_x R_e(y; \mathbf{\Lambda}, \mathbf{\Lambda}^*), \tag{6}$$

where $I_x \in \{0, 1\}$ is the indicator of firm's exporting behavior ($I_x = 1$ if and only if firm exports), while R_e stands for the revenue of an exporting firm and is given by

$$R_e(y; \mathbf{\Lambda}, \mathbf{\Lambda}^*) \equiv \max_{y_d + y_x \leq y} \left[R(y_d; \mathbf{\Lambda}) + R\left(\frac{y_x}{\tau}; \mathbf{\Lambda}^*\right) \right]. \tag{7}$$

A firm chooses to export if and only if

$$R_e(y; \mathbf{\Lambda}, \mathbf{\Lambda}^*) - R(y; \mathbf{\Lambda}) \geq f_e. \tag{8}$$

It can be shown that the left-hand side of (8) increases with y, hence there exists a threshold value of output $\tilde{y} > 0$ such that the firm chooses to export if and only if $y > \tilde{y}$.

Production Technology

Following Helpman et al. (2010), we define firm's production function as follows

$$y = \theta \bar{a} h^{\gamma}, \ \gamma \in (0, 1), \tag{9}$$

where θ is firm's productivity, h is the mass of workers hired by the firm, and $\bar{a}$ is the average ability of workers hired.

Combining (9) with (6), we redefine firm's revenue as follows

$$R(h, \theta, \bar{a}) \equiv \mathcal{R}(\theta \bar{a} h^{\gamma}) \tag{10}$$

Following the duality principle, we define a variable production cost as follows

$$C(y; \bar{a}, \theta, w) \equiv w \left(\frac{y}{\theta \bar{a}}\right)^{1/\gamma} \tag{11}$$

For a non-exporting firm, the markup is given by

$$m \equiv \frac{p - \partial C/\partial y}{p}$$

For an exporting firm, the markups are

$$m_d \equiv \frac{p_d - \partial C/\partial y}{p_d}, \quad m_x \equiv \frac{p_x - \partial C/\partial y}{p_x}$$

Note that the firm can charge different markups at home and foreign markets.

2.3 Labor market

A worker is endowed with a specific level of ability a drawn from a distribution $G(a)$. Firms do not observe a, but know $G(\cdot)$. In contrast to Helpman et al. (2010) we do not assume any parametric specification of G.

Each firm chooses the mass n of workers to be interviewed. Search requires a constant cost $b > 0$ for an additional worker to be interviewed. Even though a is not observable, the firm can set up a screening process that allows to find out whether the worker's ability exceeds a *screening threshold* a_c chosen by the firm. The firm bears screening costs $S(a_c)$, which are assumed to satisfy $S'(a_c) > 0$, $S''(a_c) \geq 0$, and hires a worker if and only if $a > a_c$. Thus, the mass of hired workers is determined as $h = [1 - G(a_c)]n$, while the average ability of workers within the firm is given by

$$\bar{a} = \frac{\int_{a_c}^{\infty} a \mathrm{d}G(a)}{1 - G(a_c)} \tag{12}$$

In other words, average ability within the firm is the mean of distribution G, truncated at the level a_c.

Wage bargaining process

We now come to the wage determination process. We assume that, given n and a_c (hence h and $\bar{a}$), each firm is involved in a bargaining game with its potential workers. To describe the bargaining process, we use the approach proposed by (Stole and Zwiebel, 1996). This approach takes into account that a firm internalizes potential gains or losses from re-negotiation, which arise when the number of workers changes (e.g. if an applicant leaves without achieving an agreement on the wage). As a consequence, it must be that, given θ and $\bar{a}$, the negotiated wage $w_{\text{neg}}(h, \theta, \bar{a})$ satisfies the following equation:

$$\frac{\partial R}{\partial h} = w + \frac{\partial (wh)}{\partial h} \quad \text{for all } h > 0. \tag{13}$$

Equation (13) brings together two ideas. First, the wage-setting game results in firm's marginal benefits $\partial R/\partial h$ of hiring an extra worker being equal to marginal hiring costs. Second, firms internalize re-negotiation effects captured by the second term of the right-hand side of (13): in addition to the wage w paid to an extra worker, marginal hiring cost includes a change in total wage bill $\partial(wh)/h$.

Solving (13), we find that the total wage bill is given by

$$hw_{\text{neg}}(h,\theta,\bar{a}) = R(h,\theta,\bar{a}) - \frac{1}{h}\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi \tag{14}$$

Claim. *The negotiated wage decreases with h if and only if $R(h,\theta,\bar{a})$ is concave in h.*

See Appendix 1 for deriving (14), as well as for the proof of the Claim.

Denote through $\beta(h,\theta,\bar{a})$ the *bargaining power* of firm θ, measured as the share of revenue attributed to firm θ:

$$\beta(h,\theta,\bar{a}) \equiv \frac{R(h,\theta,\bar{a}) - hw_{\text{neg}}(h,\theta,\bar{a})}{R(h,\theta,\bar{a})}. \tag{15}$$

It is worth noting that, unlike in HIR, firms' bargaining power is no longer constant, it now varies with h. Indeed, combining (14) with (15), we obtain

$$\beta(h) = \frac{\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi}{hR(h,\theta,\bar{a})}. \tag{16}$$

Do larger (in terms of h) firms always enjoy higher bargaining power in the wage setting process than the smaller ones? We show in Appendix 1 that the elasticity of β with respect to h is given by

$$\mathcal{E}_h(\beta) \equiv \frac{\partial\beta}{\partial h}\frac{h}{\beta} = \frac{\int_0^h R(\xi,\theta,\bar{a})\left[\mathcal{E}_\xi(R) - \mathcal{E}_h(R)\right]\mathrm{d}\xi}{\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi}. \tag{17}$$

Inspecting (17), we come to a proposition.

Proposition 1. *Given θ and $\bar{a}$, firms' bargaining power increases (decreases) with the number of workers if the elasticity of revenue $\mathcal{E}_h(R)$ is a decreasing (increasing) function of h.*

Recall that

$$R(h,\theta,\bar{a}) = \theta\bar{a}h^\gamma\Delta(\theta\bar{a}h^\gamma).$$

Hence, we have $\mathcal{E}_h(R) = \gamma\left[1-\eta(y)\right]$, which implies the following corollary of Proposition 1.

Corollary. *Given θ and $\bar{a}$, firms' bargaining power increases (decreases) with the number of workers if the inverse demand elasticity $\eta(y)$ is an increasing (decreasing) function of y.*

This result clearly shows that it is the demand side which is crucial for the wage bargaining outcome.

As shown by Figure 1, the relationship between the amount of labor and firm's bargaining power is essentially positive. This provides indirect evidence that assuming CES utility may be too restrictive for theoretical predictions of HIR to data.

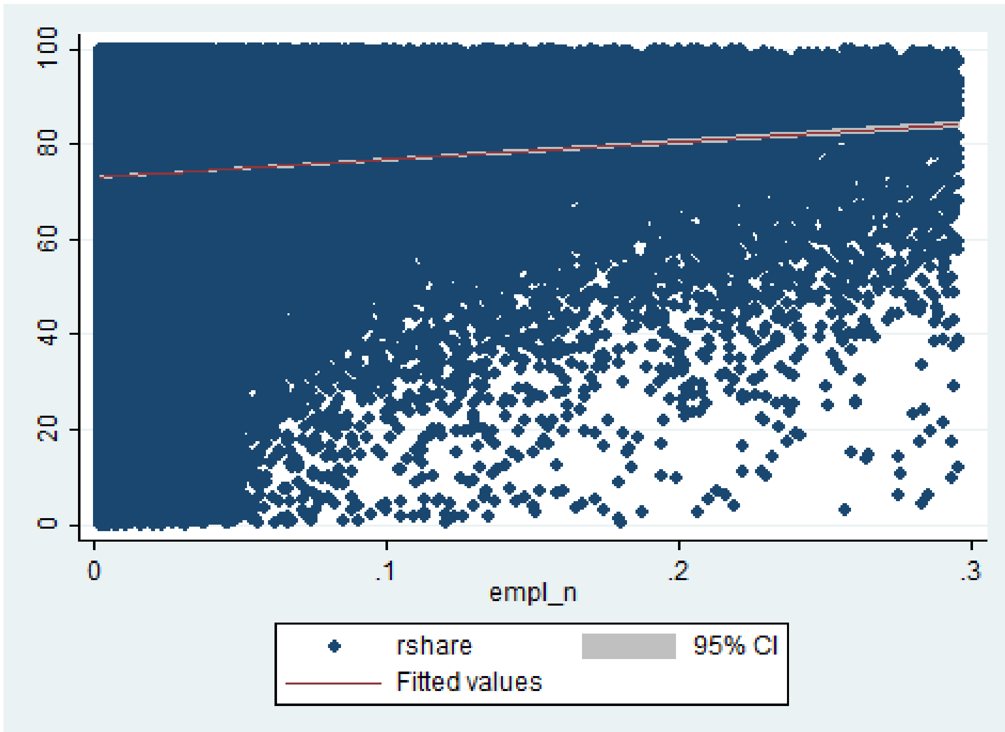

Fig. 1. Amount of labor vs bargaining power.

2.4 Profit maximization

Each firm chooses how many workers to interview n, how many workers to hire h, screening threshold a_c, and the decision whether to export I_x in order to maximize profit

$$\pi = R(h, \theta, \bar{a}) - wh - bn - S(a_c) - f_d - f_e I_x$$

Using $h = [1 - G(a_c)]n$, (12), as well as (13), the firm's problem may be reformulated as follows

$$\max_{a_c, h, I_x} \left[\frac{1}{h} \int_0^h R(\xi, \theta, \bar{a}) \mathrm{d}\xi - \frac{bh}{1 - G(a_c)} - S(a_c) - f_d - f_e I_x \right] \tag{18}$$

The first order condition $\partial \pi / \partial h = 0$ yields

$$w = b/(1 - G(a_c)) \tag{19}$$

The intuition behind (19) is as follows. According to Stole and Zweibel bargaining procedure, the firm's marginal benefit of having one more worker is equal to w. On the other hand, given the screening threshold a_c, $b/(1-G(a_c))$ is a marginal replacement cost. Thus, (19) states that at the optimal level of employment, the firm equates the marginal cost and marginal benefit of hiring a worker. It also implies that the profit maximizing level of the total wage bill is equal to the total search cost. Another important message sent by (19) is that firms making tougher requirements typically pay higher wages – there is an increasing relationship between w and a_c, independent from the other endogenous variables. As a consequence, wage is uniquely pinned down by the screening threshold, regardless of the other decisions of the firm on production and exporting.

Setting $\partial\pi/\partial a_c = 0$, we obtain

$$\frac{g(a_c)}{1-G(a_c)}\left[\left(1-\frac{a_c}{\bar{a}}\right)\frac{1}{\gamma}-1\right]\frac{w}{S'(a_c)} = \left(\frac{\theta}{y}\right)^{1/\gamma} \tag{20}$$

Equation (12) defines a one-to-one relationship between a_c and $\bar{a}$. Combining this with (19), we may restate (20) as follows

$$\frac{\theta}{y} = \phi(w) \tag{21}$$

where

$$\phi(w) = \left[\frac{g(a_c(w))}{1-G(a_c(w))}\left(\left(1-\frac{a_c(w)}{\bar{a}(a_c(w))}\right)\frac{1}{\gamma}-1\right)\frac{w}{S'(a_c(w))}\right]^{\gamma}$$

It can be shown that $\phi'(w) > 0$ when (i) G is Pareto, while S is power function or (ii) G is exponential, while S is linear. Under these circumstances, output and wages are negatively correlated for firms with the same productivity level. Combining (21) with production function equation (9), this can be interpreted as a downward-sloping demand for labor

$$h^*(w) = \left(\frac{1}{a(a_c(w))\phi(w)}\right)^{1/\gamma} \tag{22}$$

It is worth-noting that this demand is the same for all firms, because it is independent of θ. However, this property depends crucially on the power specification of production function.

2.5 Wage-productivity equation

Equation (21) can be rewritten as follows

$$\ln w = \Psi(\ln\theta - \ln y) \tag{23}$$

Furthermore, it can be shown that the profit-maximizing markups for a non-exporting firm satisfy the standard monopoly pricing rule

$$m = \eta(y), \tag{24}$$

where $\eta(y)$ is the *inverse aggregate demand elasticity*:

$$\eta(y) \equiv -\frac{\partial \Delta}{\partial y}\frac{y}{\Delta} \tag{25}$$

Using (24) and a linear Taylor approximation of (23), we obtain

$$\ln w \approx \ln \bar{w} + \delta_\theta(\ln\theta - \ln\bar{\theta}) + \delta_m(\ln m - \ln \bar{m}) \tag{26}$$

where

$$\delta_\theta = \Psi'(\ln\bar{\theta} - \ln\bar{y}), \quad \delta_m = -\delta_\theta \frac{\eta(\bar{y})}{\bar{y}\eta'(\bar{y})}. \tag{27}$$

Notice that $\frac{\delta_m}{\delta_\theta} = -\frac{\bar{y}\eta'(\bar{y})}{\eta(\bar{y})}$ is the superelasticity of inverse aggregate demand as defined by Klenow and Willis (2006). Thus, our model suggests a natural estimator of superelasticity, different from the one used by Nakamura and Zerom (2010).

Equation (26) can be estimated using a log-linear regression. Moreover, it follows immediately from (27) that (i) $\delta_\theta > 0$, (ii) $\delta_m > 0$ if and only if $\eta(y)$ is an increasing function of y, (iii) $\delta_\theta + \delta_m = 0$ if and only if $\frac{\bar{y}\eta'(\bar{y})}{\eta(\bar{y})} = 1$. The last condition holds regardless of a specific value of $\bar{y}$ if and only if η is linear in y, which is equivalent to $\Delta(y) = A\exp(-\kappa y)$. In other words, inverse aggregate demand varies with y as if it was generated by a representative consumer with CARA utility: $u(q) = 1 - \exp(-\kappa q)$. (see Behrens and Murata (2007) for details).

For exporting firms domestic and exporting markups are given by

$$m_d = \eta(y_d), \quad m_x = \eta\left(\frac{y_x}{\tau}\right). \tag{28}$$

Linearizing (23), we obtain

$$\ln w \approx c + \delta_\theta \ln\theta + \delta_M \ln m \tag{29}$$

where $m = m_d^{\frac{\alpha}{\alpha+\beta}} m_x^{\tau\frac{\beta}{\alpha+\beta}}$ is a composite markup and

$$\delta_\theta = \Psi'(\ln\bar{\theta} - \ln\bar{y}), \quad \delta_m = -\delta_\theta(\alpha+\beta) \tag{30}$$

$$\alpha = \frac{\eta(\bar{y}_d)}{\bar{y}_d\eta'(\bar{y}_d)}\frac{\bar{y}_d}{\bar{y}}, \quad \beta = \frac{\eta(\bar{y}_x)}{\bar{y}_x\eta'(\bar{y}_x)}\frac{\bar{y}_x}{\bar{y}}$$

It is clear that markups are endogenously determined within the model. First, they depend on exogenous trade costs τ. Second, note that aggregate demand elasticity η also depends on Λ and Λ^*. This justifies including observable trade costs measures and market aggregates statistics, such as aggregate demand and income inequality, as instruments that generate exogenous variability in the markups across firms.

3 Data

We test the predictions of the model using a sample of Ukrainian firm-level data from 2001 to 2007. We restrict our sample to manufacturing firms (NACE Section "D") with 20 or more workers.[1] We further exclude observations with zero or negative output, capital stock or employment. As the measure of output, Y, we use "Net sales after indirect taxes" from the Financial Results Statement. The Balance Sheet Statement is the source of the capital measure, K, for which we use "End-of-year value of tangible assets." Employment (L), material costs (M), and investment (I) come from the Enterprise Performance Statement. Employment is measured as the "Year-averaged number of enlisted employees". For investment, we use "Investments in tangible assets."

The full dataset contains over 18,000 manufacturing firms with average employment of 208 employees. However, only approximately 10,000 manufacturing firms report the Annual Sectoral Expenditures Statement (in 2007, this number fell to 2,700 firms due to a change in the sample composition). Average employment of reporting manufacturing firms in the restricted sample is 334 workers. These firms produced over 75% of the annual manufacturing output of Ukraine (which fell to 60% in 2007). Detailed material costs, firm's expenditures on purchases from 22 manufacturing industries and 15 service sub-sectors were used to construct firm-specific indices of services liberalization for the restricted sample, which were used as instruments for productivity.

Output measure is deflated by two-digit sub-sector price deflators. Capital, investments and material costs are deflated by PPI. Based on the files accompanying the Enterprise Performance Statement and the Balance Sheet Statement, we have created a comprehensive profile for every firm, which includes the territory code and the four-digit industry code, fully compatible with NACE classification. Annual FDI statements let us identify firms with foreign ownership, defined as ownership of more than 10 percent of the company by a foreigner. We used annual customs data to define export to sales share and importing status of a firm. Also, we have created entry and exit indicator variables, marking the entry as the first year when a firm appeared in the sample, and the exit as the last year. Periods between exit and entry were marked as zeros, even though a firm could disappear from the sample for some years. In year 2007, the value of the exit variable was assumed to be zero, to be consistent with Olley and Pakes (1996). Similarly, the entry variable was assumed to be zero for all firms in 2001. The descriptive statistics for the full and restricted samples are presented in Table 1.

[1] Our results for all manufacturing firms do not differ neither in statistical significance nor in size of the coefficient point estimates. Results are available upon request.

Variable	Observations	Mean	Std. deviation
A. Summary statistics. Full sample			
w_{it} per worker, thsd UAH 2001	74989	4.613	3.653
Y_{it}, thsd. UAH 2001	74989	15413	143590
L_{it}, workers	74989	208.1	1092
K_{it}, thsd. UAH 2001	74264	5333	39610
M_{it}, thsd. UAH 2001	74263	9877	116846
I_{it}, thsd. UAH 2001	49327	1797	18318
$\ln(TFP_{i,t})$	69219	1.094	1.401
va_{it}/L_{it}	74263	20	43.77
$\text{Importer}_{i,t}$	74989	0.2534	0.435
$\text{Export to sales}_{i,t}$	74989	.1039	.2449
$\text{Foreign}_{i,t}$	74989	0.0766	0.266
$\text{Exit}_{i,t}$	74989	0.02772	0.1642
$\text{Entry}_{i,t}$	74989	0.05119	0.2204
Urban_{i}	74989	0.7115	0.4531
$\text{Private}_{i,t}$	74989	0.9274	0.2594
Single plant_{it}	74989	0.9573	0.2022
B. Summary statistics. Restricted sample			
w_{it} per worker, thsd UAH 2001	40562	5.074	3.979
Y_{it}, thsd. UAH 2001	40562	26066	192037
L_{it}, workers	40562	333.8	1451
K_{it}, thsd. UAH 2001	40562	9099	52871
M_{it}, thsd. UAH 2001	40562	16909	156834
I_{it}, thsd. UAH 2001	32377	2486	22339
$\ln(TFP_{i,t})$	40562	1.073	1.357
va_{it}/L_{it}	40562	23.52	52.29
$\text{Importer}_{i,t}$	40562	0.3452	0.4754
$\text{Export to sales}_{i,t}$	40562	.1342	.2651
$\text{Foreign}_{i,t}$	40562	0.096	0.2946
$\text{Exit}_{i,t}$	40562	0.01985	0.1395
$\text{Entry}_{i,t}$	40562	0.01723	0.1301
Urban_{i}	40562	0.6874	0.4636
$\text{Private}_{i,t}$	40562	0.8958	0.3055
Single plant_{it}	40562	0.9292	0.2564
Input tariff_{it}	40562	4.918	3.151
Serv. Lib_{it} (EBRD)	40562	0.3506	0.5376

4 Empirical strategy

The empirical counterpart of equations (26) and (29) is

$$\ln w_{it} = \alpha + \delta_\theta \ln \theta_{it} + \delta_m \ln m_{it} + \delta_{exp} \times export_{it} + \delta_{\theta exp} \times export_{it} \ln \theta_{it} + X_{it}\gamma + D_{st}s + D_r r + \epsilon_{it} \tag{31}$$

where w_{it} is firm $i's$ average wage at time t. θ_{it} is firm $i's$ measured productivity at time t. m_{it} is firm $i's$ average markup, $export_{it}$ is the share of export to sales. D_{st} are industry-year fixed effects, and D_r are region fixed effects. X represents a vector of additional controls.

Based on the theory developed in the previous section, we expect $\delta_\theta > 0$, which reflects the well-documented stylized fact that more productive firms pay higher wages (Amiti and Davis, 2012). However, the behavior of δ_m is more versatile. It increases (decreases) with markups if and only if inverse demand elasticity is a decreasing (increasing) function of y, i.e. when larger firms charge lower (higher) markups.

4.1 Productivity measures

In the empirical analysis we use two measures of productivity – labor productivity and total factor productivity (TFP). Labor productivity is constructed as the value added deflated by the industry price deflator divided by the number of workers. To recover the TFP measure, we estimate the production function for each manufacturing industry (2-digit NACE classification) by the Olley-Pakes procedure (Olley and Pakes, 1996), controlling for the sub-industry-specific demand and price shocks as suggested by De Loecker (2011). We identify the demand and price shocks by exploiting variation in sub-industry (4-digit NACE classification) output at time t and by controlling for sub-industry and time fixed effects. As a new result, we demonstrate the De Loecker methodology is valid under non-CES preferences.

TFP estimation

Consider a production technology of a single-product firm i at time t described by production function

$$Y_{it} = L_{it}^{\alpha_l} K_{it}^{\alpha_k} M_{it}^{\alpha_m} \exp(\tilde{\omega}_{it} + \tilde{u}_{it}), \tag{32}$$

where Y_{it} units of output are produced using L_{it} units of labor, K_{it} units of capital, and M_{it} units of material and services inputs. $\tilde{\omega}_{it}$ is firm-specific productivity that includes both technical efficiency and workers' average ability, unobservable by an econometrician, but known to the firm before it chooses variable input L_{it}. $\tilde{u}_{it}$ is an idiosyncratic shock to production that also captures measurement error introduced due to unobservable input and output prices.

Output Y_{it} is not observed, because we do not know firm-specific prices p_{it}. Observable sales,

$R_{it} = p_{it}Y_{it}$, reflect differences in physical quantities as well as variation in markups across firms within the same industry. Therefore, use of R_{it} as the dependent variable in estimation of production function parameters, without controlling for prices, determined among other things by market structure and demand shocks, would bias estimates of the production function if prices are correlated with inputs.

To deal with this issue, we introduce the following inverse demand system:

$$p_{it} = \frac{u_s'(Y_{it})}{\lambda_{st}} \exp(\tilde{\xi}_{it}), \quad i \in I_s \tag{33}$$

where I_s is the set of firms in industry s, Y_{it} is the output of firm $i \in I_s$ in the period t, $u_s(\cdot)$ is the utility function specific for industry s, $\tilde{\xi}_{it}$ is a random shock in demand, while λ_{st} is the Lagrange multiplier of the consumer's problem.

Taking logs and rearranging (33) yields

$$\ln Y_{it}u_s'(Y_{it}) - \ln Y_{it}p_{it} = \ln \lambda_{st} + \tilde{\xi}_{it}.$$

Setting $R_{it} \equiv Y_{it}p_{it}$, we get

$$\ln R_{it} = \ln Y_{it}u_s'(Y_{it}) - \ln \lambda_{st} + \tilde{\xi}_{it} \tag{34}$$

Let Y_{st} be total consumer's expenditure on products in industry s at time t. Then, using (33) and the consumer's budget constraint $\sum_{j \in I_s} p_{it}Y_{it} = Y_{st}$, we implicitly define $\lambda_{st} = \Lambda(Y_{st}, \mathbf{p}_{st})$ by

$$Y_{st} = \sum_{j \in I_s} p_{jt} \left(u_s'\right)^{-1} (\lambda_{st}p_{jt}). \tag{35}$$

To estimate (34), we log-linearize it in the neighbourhood of the average point $\left(\bar{\mathbf{p}}_s, \bar{Y}_s\right)$, where

$$\bar{\mathbf{p}}_s \equiv \left(\frac{1}{|I_s|}\sum_{j \in I_s} p_{jt}\right) \cdot \mathbf{1}, \quad \bar{Y}_s \equiv \frac{1}{|I_s|}\sum_{j \in I_s} Y_{jt}.$$

Doing so, we obtain

$$\ln R_{it} \approx \text{const} + (1 + r_u(\bar{Y})) \ln Y_{it} - \left.\frac{\partial \ln \Lambda}{\partial \ln Y_{st}}\right|_{\text{avg}} \ln Y_{st} - \sum_{j \in I_s} \left.\frac{\partial \ln \Lambda}{\partial \ln p_{jt}}\right|_{\text{avg}} \ln p_{jt} + \tilde{\xi}_{it}. \tag{36}$$

Here and in what follows $\left.(\cdot)\right|_{\text{avg}}$ means that the elasticities are evaluated at $\left(\bar{\mathbf{p}}_s, \bar{Y}_s\right)$.

Thus, we need to know the elasticities of Λ with respect to Y_{st} and p_{it}. Implicitly differentiating (35), we obtain

$$\frac{\partial \ln \Lambda}{\partial \ln Y_{st}} = -\left[\sum_{j \in I_s} \frac{\theta_{jt}}{\eta_{jt}}\right]^{-1}, \quad \frac{\partial \ln \Lambda}{\partial \ln p_{it}} = -\frac{1 - \eta_{it}}{\eta_{it}} \left(\sum_{j \in I_s} \frac{\theta_{jt}}{\theta_{it}} \frac{1}{\eta_{jt}}\right)^{-1}, \tag{37}$$

where $\eta_{jt} \equiv -Y_{jt}u''(Y_{jt})/u'(Y_{jt})$ is the inverse demand elasticity evaluated at Y_{jt}, while $\theta_{jt} \equiv \frac{p_{jt}Y_{jt}}{Y_{st}}$ is the share of total expenditure spent on product j at time t. At the average point, i.e. when $p_{jt} = \bar{p}$, $Y_{jt} = \bar{Y}_s$, formulas (37) boil down to

$$\left.\frac{\partial \ln \Lambda}{\partial \ln Y_{st}}\right|_{\text{avg}} = -\eta(\bar{Y}_s), \qquad \left.\frac{\partial \ln \Lambda}{\partial \ln p_{it}}\right|_{\text{avg}} = -\frac{1-\eta(\bar{Y}_s)}{|I_s|}. \tag{38}$$

Hence, the log-linear Taylor approximation of $\Lambda(Y_{st}, \mathbf{p})$ in a small neighbourhood of the average point is given by

$$\ln \Lambda(Y_{st}, \mathbf{p}) \approx \text{const} - \eta(\bar{Y}_s) \ln Y_{st} - [1 - \eta(\bar{Y}_s)] \frac{1}{|I_s|} \sum_{j \in I_s} \ln p_{jt}. \tag{39}$$

Plugging (39) into (36), we obtain

$$\ln(R_{it}/P_{st}) \approx \text{const} + (1 + \eta(\bar{Y}_s)) \ln Y_{it} - \eta(\bar{Y}_s) \ln(Y_{st}/P_{st}) + \tilde{\xi}_{it}, \tag{40}$$

where P_{st} is the price index defined as a simple geometric average of prices in industry s:

$$P_{st} \equiv \left(\prod_{j \in I_s} p_{jt} \right)^{\frac{1}{|I_s|}}.$$

Finally, combining (40) with the production function (32), we come to

$$r_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_m mat_{it} + \beta_s y_{st} + \omega_{it} + \xi_{it} + u_{it}, \tag{41}$$

where $r_{it} = \ln(R_{it}/P_{st})$ is log of revenue deflated by corresponding industry (NACE 2 digit) price deflator and the other lower-case letters represent upper-case variables in the log form. $\beta_f = \frac{\sigma_s+1}{\sigma_s}\alpha_f$, where $f = \{l, k, mat\}$. The elasticity of substitution in industry s can be retrieved as $\sigma_s = 1/\eta(\bar{Y}_s) = -1/\beta_s$. Finally, $\omega_{it} = \frac{\sigma_s+1}{\sigma_s}\tilde{\omega}_{it}$, $\xi_{it} = -\frac{1}{\sigma_s}\tilde{\xi}_{it}$, and $u_{it} = \frac{\sigma_s+1}{\sigma_s}\tilde{u}_{it}$ are error terms. In what follows, we suppress the sector index for clarity of presentation.

We estimate equation (41) separately, for each manufacturing industry, using the Olley-Pakes methodology (Olley and Pakes, 1996) and accounting for demand shocks as outlined above. Instead of using total industry output, we use more disaggregated sub-industry g output (NACE 4 digit), y_{gt}, to add more variability to the estimation of σ_s. We decompose the overall demand shock into the following components

$$\xi_{it} = \xi_t + \xi_g + \tilde{\xi}_{it}, \tag{42}$$

where ξ_t is industry-specific shock common to all firms at time t, ξ_g is demand factor affecting only firms producing in sub-industry g, and $\tilde{\xi}_{it}$ is an idiosyncratic shock. Plugging in (42) in (41), we obtain the following equation

$$r_{it} = \beta_l l_{it} + \beta_k k_{it} + \beta_m mat_{it} + \beta y_{gt} + \delta_t D_t + \delta_g D_g + \omega_{it} + \varepsilon_{it} \tag{43}$$

where D_t is a a year fixed effect and D_g is a sub-industry fixed-effect. $\varepsilon_{it} = \tilde{\xi}_{it} + u_{it}$ is the error term which is not correlated with inputs and productivity.

Results of the estimation are presented in Table 2. Total factor productivity net of price and demand effects is recovered as

$$\ln \theta_{it} = (r_{it} - \beta_l l_{it} - \beta_k k_{it} - \beta_m mat_{it} - \beta_s y_{st}) \frac{\sigma_s}{\sigma_s + 1}. \tag{44}$$

4.2 Markups

We recover firm-specific markups following a procedure developed by De Loecker and Warzynski (2012). The markups are computed as

$$\hat{m}_{it} = \frac{p_{it}}{\partial C / \partial y} = \frac{\beta_l}{\omega_{it} L_{it} / p_{it} Y_{it}}. \tag{45}$$

The procedure does not impose any assumptions on the demand side and market structure and allows a general from of the continuous and twice-differentiable production function.

To be consistent with our theoretical model, we redefine markups as follows

$$m_{it} = 1 - 1/\hat{m}_{it}.$$

Since we do not have information on how labor is used in production for different markets, this measure reflects an average markup and do not vary with market-destination.

4.3 Endogeneity of productivity and markups

Productivity

In the HIR framework, productivity is split into two components – technical efficiency θ_{it} and average ability of workers, $\bar{a}$, which is increasing with the screening intensity. Since we do not have information on $\bar{a}$, our productivity measure includes both components. Unobserved average ability is positively correlated with both wage and productivity. It means that $corr(\bar{a}, \theta) > 0$, and leads to an upward bias in estimation of δ_θ. Alternatively, in the framework of Egger and Kreickemeier (2012) and (Amiti and Davis, 2012) based on the fair wage hypothesis (Akerlof and Yellen, 1990), a wage rate below some level w^*, considered as a fair wage by workers, would lower their level of effort, e, leading to lower productivity. The positive correlation between an unobserved effort and

Industry	ln(K)		ln(L)		ln(M)		ln(Y)	Firms	N
	β_K	α_K	β_L	α_L	β_M	α_M	β_s		
15+16	0.045***	0.048	0.285***	0.303	0.647***	0.687	0.058*	7133	24720
	(0.012)	***	(0.012)	***	(0.011)	***	(0.027)		
17	-0.007	-0.007	0.356***	0.364	0.565***	0.577	0.022	787	2118
	(0.028)		(0.040)	***	(0.019)	***	(0.044)		
18	0.106**	0.112	0.487***	0.513	0.454***	0.478	0.051	1462	4458
	(0.039)	**	(0.025)	***	(0.012)	***	(0.052)		
19	0.148*	0.238	0.383***	0.616	0.550***	0.884	0.378*	411	1302
	(0.069)		(0.034)	***	(0.022)	***	(0.179)		
20	0.081***	0.087	0.297***	0.320	0.619***	0.667	0.072	2696	6438
	(0.021)	***	(0.022)	***	(0.012)	***	(0.047)		
21	0.040	0.044	0.186***	0.205	0.588***	0.649	0.095	611	1990
	(0.052)		(0.034)	***	(0.033)	***	(0.083)		
22	0.098***	0.092	0.454***	0.428	0.453***	0.427	-0.061*	4407	12520
	(0.020)	***	(0.021)	***	(0.010)	***	(0.028)		
23	-0.124*	-0.124	0.218*	0.218	0.492***	0.491	-0.002	213	634
	(0.060)	*	(0.089)	*	(0.054)	***	(0.107)		
24	0.133***	0.145	0.259***	0.283	0.563***	0.616	0.086*	1539	4998
	(0.034)	***	(0.030)	***	(0.024)	***	(0.039)		
25	0.094***	0.103	0.282***	0.307	0.590***	0.643	0.083	1944	5867
	(0.027)	***	(0.018)	***	(0.015)	***	(0.043)		
26	0.047	0.050	0.285***	0.303	0.628***	0.668	0.059	2874	8993
	(0.034)		(0.022)	***	(0.017)	***	(0.032)		
27	0.034	0.040	0.213***	0.252	0.636***	0.753	0.155***	656	2148
	(0.041)		(0.035)	***	(0.031)	***	(0.033)		
28	0.092***	0.098	0.303***	0.324	0.575***	0.614	0.064	3199	8324
	(0.018)	***	(0.018)	***	(0.016)	***	(0.037)		
29	0.080***	0.082	0.406***	0.420	0.442***	0.457	0.033	4477	13536
	(0.010)	***	(0.014)	***	(0.010)	***	(0.028)		
30	0.221**	0.150	0.691***	0.468	0.341***	0.231	-0.477	495	1100
	(0.076)	*	(0.061)	***	(0.026)	***	(0.277)		
31	0.097**	0.103	0.326***	0.348	0.456***	0.487	0.065	1750	5265
	(0.033)	**	(0.021)	***	(0.015)	***	(0.047)		
32	0.150*	0.155	0.328***	0.340	0.414***	0.429	0.035	671	1850
	(0.067)	*	(0.046)	***	(0.026)	***	(0.130)		
33	0.065	0.064	0.418***	0.415	0.431***	0.428	-0.006	1097	3256
	(0.039)		(0.028)	***	(0.017)	***	(0.077)		
34	0.150*	0.167	0.234***	0.261	0.540***	0.601	0.102*	422	1297
	(0.071)	*	(0.053)	***	(0.052)	***	(0.051)		
35	-0.030	-0.042	0.442***	0.605	0.406***	0.556	0.270***	755	2485
	(0.033)		(0.044)	***	(0.027)	***	(0.064)		
36	0.085**	0.090	0.345***	0.362	0.578***	0.607	0.048	2035	5689
	(0.027)	**	(0.025)	***	(0.017)	***	(0.036)		
37	0.085	0.123	0.628***	0.914	0.280***	0.408	0.313*	869	2264
	(0.068)		(0.059)	***	(0.027)	***	(0.150)		

Notes: * $p<0.05$, ** $p<0.01$, *** $p<0.001$. Bootstrap standard errors are presented in parentheses. Table reports point estimates of revenue function parameters, β and production function paramters $\alpha = \frac{\sigma_s}{\sigma_s+1}\beta$, where $\sigma_s = -1/\beta_s$ for Ukrainian manufactruing firms for 2001-2007. Each row in the table represents Olley-Pakes estimation of production function for each 2 digit manufacturing productivity, $corr(e, \theta) > 0$, leads to a positive bias in the OLS estimation of the coefficient δ_θ.

To estimate equation (31) consistently, a source of exogenous variation in productivity is needed. We propose a well-known link from deregulation to productivity as such variation. Recent studies of services and trade liberalization Amiti and Konings (2007); Arnold et al. (2011); Fernandes and Paunov (2011); Khandelwal and Topalova (2011) find positive effect of the liberalization on productivity of manufacturing firms. The size of the effect varies across firms because of differences in intensity, with which firms use liberalized goods and services as inputs.

We use the episode of the Ukrainian trade and services liberalization in 2001-2007, isolated from other major deregulatory changes and driven by political pressure imposed by Ukraine's trading partners as a precondition for the Ukrainian WTO accession. Concerning services, the government developed new laws and amended existing ones that regulated activities of TV and broadcasting, information agencies, banks and banking activities, insurance, telecommunications, and business services. It led to differentiated but positive effect on productivity in the downstream manufacturing firms (Shepotylo and Vakhitov, 2012). The results indicate that a standard deviation increase in services liberalization is associated with a 9.2 percent increase in TFP. In parallel with the services liberalization, the WTO negotiations also led to further liberalization of trade in goods, which also had a positive effect on productivity.

In what follows we descirbe construction of instruments related to endogeneity of productivity measure. The index of services liberalization is firm-specific, reflecting the variation in firm-level intensity of usage of various services inputs. Similarly to Arnold et al. (2011), but using firm level data, the index is computed according to the following formula

$$serv\,lib_{it} = \sum_j a_{it}^j \times index_t^j \tag{46}$$

where a_{it}^j is the share of input sourced from the services sub-sector j in the total input for a firm i at time t, and $index_t^j$ is the measure of liberalization in the service sub-sector j at time t. The constructed index of services liberalization is further divided by a standard deviation for normalization. We proxy for $index_t^j$ by structural change indicators provided by the European Bank for Reconstruction and Development (EBRD).[2]

The second instrument captures the firm-specific measure of trade liberalization. We compute an index of input tariff liberalization following Amiti and Konings (2007):

$$input\,tariff_{it} = \sum_s b_{it}^s \times tariff_t^s \tag{47}$$

where $input\,tariff_{it}$ is the firm-specific input tariff measure, b_{it}^s is the share of input sourced from the two-digit NACE industry s in the total input for firm i at time t, and $tariff_t^s$ is the

[2]EBRD structural change indicators are available at http://www.ebrd.com/pages/research/economics/data/macro.shtml. The mapping from the structural change indicators to sub-sectors of services is explained in the appendix.

trade-weighted average MFN import tariff in industry s at time t.

Markups

The constructed markups are endogenously determined as a function of wages. Since $corr(\frac{p_{it}}{\theta_{it}}, \epsilon_{it}) < 0$, the OLS estimation of (31) would lead to a downward bias in the estimation of the markup coefficient. According to equation (28), $\ln m = \frac{\alpha}{\alpha+\beta} \ln m_d + \tau \frac{\beta}{\alpha+\beta} \ln m_x$, where domestic and foreign markups depend on domestic and foregin market sizes. Using firm-level export statistics, we use construct two instruments to cope with endogeneity of markups. First, we construct a proxy for the trade costs as the export-weighted average distances $\hat{\tau_{it}} = \sum_j \frac{exp_{ijt}}{exp_{it}} \ln dist_{ij}$ to destination markets, where exp_{ijt} is export of firm i to country j at time t, $exp_{it} = \sum_j exp_{ijt}$ is the total export of firm i at time t, and $dist_{ij}$ is distance from Ukraine to country j. Second, we construct a proxy for the market size as $\hat{MP_{it}} = \sum_j \frac{exp_{ijt}}{exp_{it}} \ln GDP_{jt}$, where $GDP_{jt}$is gross domestic product of country j at time t. We normalize $\ln m_d$ as equal to zero, so $\ln m = 0$ for non-exporting firms.

5 Results

Dynamics of labor productivity, TFP, markups, and wages in 2001-2007 is presented in Table 3. Over the investigated period, productivity has almost doubled, while dispersion of productivity has been moderately growing. Markups have also increased, but without noticeable trend in variation. An increase in the markups during the trade and services liberalization episode is consistent with findings of De Loecker et al. (2012) – during the trade liberalization episode in India, marginal costs have been reduced by 40 percent, while prices fell only by 16.8 percent, leading to higher markups.

5.1 OLS

We first estimate equation (31) by OLS. We control for the structural changes in the economy by including industry-time specific effects. The errors are corrected for heteroskedasticity at the firm level. The results are presented in Table 4. First, we regress $\ln w_{it}$ on the measured labor productivity and other controls, ignoring the variation in markups. Column (1) of Table 4 shows that a 10 percent increase in labor productivity is associated with 2.95 percent increase in wage. Once we include markups in column 2, the coefficient on labor productivity is almost doubled, while the coefficient on the markup is negative and significant. Comparing results in columns (1) and (2), points to the omitted variable bias for the model specification in column (1). At the same time, the model specified in column (2) has two endogenous variables – productivity and markups – causing an upward bias in the OLS estimation of the coefficient on productivity, while the estimation of the coefficient on the markup is biased downward. Inclusion of firm-specific effects in column (3) of the table alleviates endogeneity problem, resulting in the coefficient on labor productivity almost

Year	$\ln va_{it}/L_{it}$		$\ln \theta_{it}$		$\ln m_{it}$		$\ln w_{it}$	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
			A. Full sample					
2001	1.74	1.375	0.815	1.413	0.757	0.96	0.82	0.758
2002	1.951	1.2	0.915	1.409	0.644	0.963	1.045	0.694
2003	2.088	1.171	0.995	1.39	0.664	1.003	1.161	0.664
2004	2.399	1.129	1.129	1.392	0.772	0.961	1.293	0.627
2005	2.578	1.076	1.19	1.359	0.757	0.925	1.48	0.599
2006	2.728	1.065	1.264	1.389	0.752	0.921	1.611	0.586
2007	2.881	1.096	1.373	1.372	0.793	0.936	1.696	0.573
Total	2.331	1.227	1.094	1.401	0.732	0.956	1.292	0.71
			B. Restricted sample					
2001	1.791	1.363	0.815	1.413	0.803	0.938	0.856	0.727
2002	2.02	1.178	0.915	1.409	0.721	0.93	1.074	0.672
2003	2.174	1.157	0.995	1.39	0.772	0.96	1.191	0.645
2004	2.457	1.11	1.129	1.392	0.827	0.942	1.323	0.61
2005	2.625	1.054	1.19	1.359	0.796	0.918	1.508	0.578
2006	2.774	1.047	1.264	1.389	0.786	0.912	1.64	0.565
2007	2.924	1.082	1.373	1.372	0.823	0.925	1.723	0.556
Total	2.394	1.208	1.094	1.401	0.789	0.933	1.326	0.689

Table 3: Productivity, markups, and wages

the same as in column (1), but the coefficient on the markup remains negative. Column (3) shows that firms that increase export to sales by a standard deviation pay a wage premium of 1.5 percent, which is well in agreement with the theoretical predictions. Adding an interaction between export status and productivity, $export_{it} \times \ln \theta_{it}$, in column (4) demonstrates that elasticity of wage with respect to productivity is statistically different for exporters and non-exporters. At the same time exporter wage premium more than doubles.

Results in column 4 also indicate that firms that start importing some of their inputs pay 3.4 percent more, which corresponds well with Amiti and Davis (2012), who found 3.2 percent increase in wage after the firm starts importing in Indonesia. Firms that switch ownership from domestic to foreign pay 3.5 percent higher wages. Exiting firms pay 7.4 percent lower wage. We also have found a positive scale effect, measured by total employment, even after controlling for productivity, market power, and export status.

Columns (5) - (8) of Table 4 show results of the regression of $\ln w_{it}$ on TFP and other controls. The results with two different productivity measures are quite similar for exogenous controls. However, the positive effect of TFP on wages and the negative effect of markup on wages are somewhat smaller in the absolute value. These results are expected because the model with labor productivity overestimates productivity for firms with high value of capital, leading to a positive correlation of errors with productivity and negative correlation of errors with markups.

5.2 IV results

In this section we report results of the estimation of equation (31) by the IV GMM method in the first differences in order to account for firms' fixed effects. We use four instruments. Two of them – services liberalization measured by EBRD indices of reforms and the input tariff liberalization measure, which are computed according to equations (46) and (47) – instrument for endogeneity of productivity measures. The other two – the weighted average of distances to five major destination countries weighted by export shares and the export-weighted GDP per exporting firm – are instruments for markups. The errors are corrected for heteroskedasticity at the firm level, all regressions include industry-time and regional fixed effects.

The results are presented in Table 5 for the labor productivity measure and in Table 6 for the TFP measure. The estimation is performed on the restricted sample. Column (1) of Table 5 presents the benchmark OLS results, which do not differ considerably from the results estimated on the full sample in column (3) of Table 4. Column (2) presents point estimates of the coefficients estimated by the instrumental variables GMM method. Relative to the results in column (1), the coefficient on labor productivity loses its significance, while the coefficient on the markup flips the sign. It confirms our theoretical priors that the OLS estimation of the coefficient on productivity is biased upward and the OLS estimation of the coefficient on the markup is biased downward. This result holds for any model specification and for any productivity measure, that are presented

Dependent variable: $\ln(w_{it})$	Labor productivity				TFP			
	OLS	Markups	FE	Exp × prod.	OLS	Markups	FE	Exp × prod.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\ln\theta_{it}$	0.295***	0.398***	0.231***	0.226***	0.325***	0.362***	0.252***	0.232***
	(0.009)	(0.014)	(0.017)	(0.016)	(0.007)	(0.008)	(0.008)	(0.008)
$\ln(m_{it})$		-0.294***	-0.199***	-0.199***		-0.089***	-0.118***	-0.125***
		(0.012)	(0.012)	(0.012)		(0.006)	(0.006)	(0.007)
$\ln\theta_{it}\times$ $\ln m_{it}$				-0.011				-0.031***
				(0.024)				(0.005)
Export to sales_{it}	0.104***	0.098***	0.064***	0.151***	0.085***	0.078***	0.075***	0.085***
	(0.014)	(0.013)	(0.014)	(0.041)	(0.016)	(0.016)	(0.015)	(0.016)
$\text{Export}_{it}\times$ $\ln\theta_{it}$				-0.036*				-0.031***
				(0.016)				(0.005)
Importer_{it}	-0.024*	-0.005	0.033***	0.034***	0.086***	0.102***	0.048***	0.051***
	(0.010)	(0.010)	(0.005)	(0.005)	(0.009)	(0.009)	(0.005)	(0.005)
Foreign_{it}	0.123***	0.110***	0.034*	0.035**	0.194***	0.196***	0.059***	0.059***
	(0.013)	(0.012)	(0.013)	(0.013)	(0.015)	(0.015)	(0.014)	(0.014)
$\ln(L_{it})$	0.118***	0.118***	0.049***	0.049***	0.133***	0.134***	0.033***	0.032***
	(0.003)	(0.003)	(0.007)	(0.007)	(0.004)	(0.004)	(0.007)	(0.007)
Exit_{it}	-0.062***	-0.125***	-0.073***	-0.074***	-0.156***	-0.183***	-0.103***	-0.103***
	(0.015)	(0.014)	(0.014)	(0.014)	(0.017)	(0.017)	(0.016)	(0.016)
Urban_{i}	0.074***	0.069***	-0.010	-0.008	0.104***	0.105***	0.010	0.011
	(0.008)	(0.007)	(0.022)	(0.022)	(0.009)	(0.009)	(0.023)	(0.023)
Industry × Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	No	No	Yes	Yes	No	No	Yes	Yes
Observations	72045	72045	72045	72045	69219	69219	69219	69219
R^2	0.578	0.630	0.546	0.548	0.503	0.509	0.510	0.514

Standard errors clustered by firms in parentheses. * $p<0.05$, ** $p<0.01$, *** $p<0.001$

Standard errors in parentheses

Table 4: OLS

in Tables 5 and 6. The sizes of the coefficients on productivity and markups are remarkable stable. For the baseline model in column 2 of Table 5, a 10 percent increase in labor productivity leads to 0.64 percent increase in wage, while a 10 percent increase in the markup leads to a 1.58 percent increase in wage.

Wage is an increasing function of export to sales. Increasing exports to sales ratio by a standard deviation increases wage by 1.4 percent. Firms that start importing their inputs pay 2.1 percent higher wages. Firms that switch to foreign ownership start paying slightly higher wage, but the effect is not significant. Elasticity of wage with respect to employment within a firm is negative and significant 0.048. Firms that move to urban areas pay slightly higher wage but the effect is not significant.

In column (3) we include an interaction term $export_{it} \times \ln \theta_{it}$. Elasticity of wage with respect to productivity is not statistically different for exporters and non-exporters. It should be noted that private firms in Ukraine pay part of the salary in cash and do not report it as the wage bill to evade the social security tax ranging from 32.6 to 49.7 percent of the wage bill. State-owned companies do not have this incentive, reporting all labor-related expenses in wage bills. This feature of the tax system leads to under-reporting of wages by the private companies and can bias our results. Column (4) reports the results with additional variable that control for state- vs. private-owned firms. Privatized firms increase wages by 9.3 percent, but it does not change our main conclusions.

Literature emphasizes distinction between multi-plant and single-plant firms. Related to this, distinction between multi-product and single-product firms is important when modeling firm's reaction to trade liberalization (Bernard et al., 2011). We control for single- vs. multi-plant firms in column (5), which has no impact on our conclusions. In column (6) we control for new entrants, which on average pay 7.3 percent lower wages than incumbents. Finally, in column (7) we include all additional controls, but it does not change our results.

Our identification strategy would fail if exclusion restrictions are not valid. For instance, trade and services liberalization can have a general equilibrium effect on wages which influences more firms that use imported goods and liberalized services more intensively. In that case our excluded variables influence wages not only through productivity, but also directly. We are quite confident that our estimation is valid for several reasons. First, we control for the industry-time specific trends directly. Second, the overidentification test does not reject validity of our instruments. To sum up, we find a robust positive effect of market power on wages, with elasticity in the range 0.158-0.163. The labor productivity also positively contributes to wages, but the effect is weaker and is not statistically significant.

As a robustness check, Table 6 reports IV results with productivity measured by TFP. In general, results are very similar to the results discussed for labor productivity. This gives us reassurance that the result does not depend on the way productivity is estimated or on the specification of production technology in the model.

Dependent variable: $\ln \omega_{it}$	(1) OLS	(2) Base	(3) Inter-action	(4) Private	(5) Single plant	(6) Entry	(7) All
D.ln θ_{it}	0.149***	0.064	0.056	0.064	0.064	0.056	0.048
	(0.006)	(0.045)	(0.043)	(0.045)	(0.045)	(0.046)	(0.044)
D.ln m_{it}	-0.146***	0.158***	0.158***	0.158***	0.158***	0.162***	0.163***
	(0.011)	(0.046)	(0.047)	(0.046)	(0.046)	(0.046)	(0.047)
D.Export to sales$_{it}$	0.068***	0.050**	0.122	0.049**	0.050**	0.050**	0.105
	(0.015)	(0.017)	(0.095)	(0.017)	(0.017)	(0.017)	(0.097)
D.Importer$_{it}$	0.027***	0.021***	0.021***	0.021***	0.021***	0.021***	0.021***
	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
D.Foreign$_{it}$	0.041**	0.019	0.020	0.019	0.019	0.019	0.020
	(0.014)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
D.ln L_{it}	-0.000	-0.048***	-0.050***	-0.048***	-0.048***	-0.055***	-0.057***
	(0.010)	(0.014)	(0.014)	(0.014)	(0.014)	(0.015)	(0.014)
D.Exit$_{it}$	-0.075***	-0.050*	-0.052*	-0.050*	-0.050*	-0.053*	-0.055*
	(0.018)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
D.Urban$_i$	0.024	0.013	0.013	0.012	0.013	0.013	0.013
	(0.019)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
D.Exporter$_{it}\times$			-0.030				-0.024
$\ln \theta_{it}$			(0.042)				(0.043)
D.Private$_{it}$				0.093**			0.093**
				(0.034)			(0.034)
D.Single plant$_{it}$					0.012		0.011
					(0.009)		(0.009)
D.Entry$_{it}$						-0.073***	-0.076***
						(0.020)	(0.019)
Industry × Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	31336	29076	29076	29076	29076	29076	29076
Hansen J statistics		1.455	1.741	1.531	1.473	1.360	1.672
p-value		0.483	0.419	0.465	0.479	0.507	0.433
R^2	0.159	0.179	0.181	0.179	0.179	0.177	0.177

Standard errors clustered by firms are reported in parentheses. * $p<0.05$, ** $p<0.01$, *** $p<0.001$

Notes: Dependent variable is D.ln($w_{i,t}$). Productivity and markup are instrumented by EBRD index of services liberalization, index of trade liberalization, weighted average of distances to five major destination countries weighted by export shares, and by the number of destination countries per exporting firm.

Table 5: IV: Labor productivity

Dependent variable: $\ln \omega_{it}$	(1) OLS	(2) Base	(3) Inter-action	(4) Private	(5) Single plant	(6) Entry	(7) All
D.ln θ_{it}	0.152***	0.069	0.075	0.069	0.069	0.064	0.069
	(0.009)	(0.044)	(0.044)	(0.043)	(0.044)	(0.044)	(0.044)
D.ln m_{it}	-0.074***	0.205***	0.204***	0.205***	0.205***	0.202***	0.202***
	(0.009)	(0.040)	(0.038)	(0.040)	(0.040)	(0.039)	(0.038)
D.Export to sales$_{it}$	0.077***	0.047**	0.063**	0.046**	0.047**	0.047**	0.061**
	(0.015)	(0.018)	(0.021)	(0.018)	(0.018)	(0.018)	(0.021)
D.Importer$_{it}$	0.029***	0.020***	0.020***	0.020***	0.020***	0.020***	0.020***
	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
D.Foreign$_{it}$	0.044**	0.023	0.023	0.023	0.023	0.023	0.023
	(0.014)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
D.ln L_{it}	-0.022*	-0.067***	-0.067***	-0.067***	-0.067***	-0.071***	-0.071***
	(0.010)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
D.Exit$_{it}$	-0.109***	-0.058*	-0.058*	-0.058*	-0.058*	-0.060*	-0.060*
	(0.019)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.023)
D.Urban$_{i}$	0.024	0.014	0.014	0.013	0.014	0.014	0.014
	(0.021)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
D.Exporter$_{it}\times$			-0.024				-0.022
ln θ_{it}			(0.023)				(0.023)
D.Private$_{it}$				0.085*			0.086**
				(0.033)			(0.033)
D.Single plant$_{it}$					-0.001		-0.002
					(0.009)		(0.009)
D.Entry$_{it}$						-0.061***	-0.062***
						(0.017)	(0.017)
Industry × Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Region FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	32325	30071	30071	30071	30071	30071	30071
Hansen J statistics		4.731	4.468	4.827	4.729	4.499	4.350
p-value		0.094	0.107	0.089	0.094	0.105	0.114
R^2	0.098	0.095	0.096	0.096	0.095	0.101	0.101

Standard errors clustered by firms are reported in parentheses. * p<0.05, ** p<0.01, *** p<0.001

Notes: Dependent variable is D.ln($w_{i,t}$). Productivity and markup are instrumented by EBRD index of services liberalization, index of trade liberalization, weighted average of distances to five major destination countries weighted by export shares, and by the number of destination countries per exporting firm.

Table 6: IV: TFP

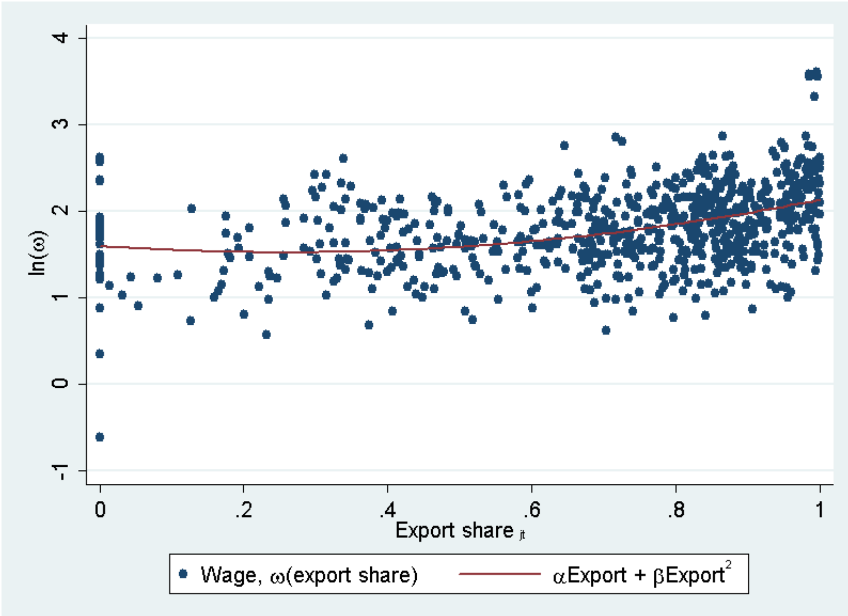

Figure 1: Average wage and share of exporters

5.3 Industry level results

Having confirmed the positive causal effect from market power to wages, we further test predictions of HIR at industry level. We aggregate our data to the level of NACE 3 digit sub-industries. We proxy $\rho = \theta_d/\theta_x$ by the share of exporters, N^x_{jt}/N_{jt}, where N^x_{jt} is the number of exporters and N_{jt} is the total number of firms in sub-industry j at time t. Figure 1 presents a scatterplot of the average wage as a function of the share of exporters. The solid line is the quadratic fit that minimizes the total sum of squared errors of the following optimization

$$\min_{c^m,\alpha^m,\beta^m}\left[\sum_{j,t}(\ln w_{jt} - c^m - \alpha^m expshare_{jt} - \beta^m expshare^2_{jt})^2\right].$$

With the exception of few outliers close to zero, the average wage increases with the share of exporters within the sub-industry.

Figure 2 presents a scatterplot of the coefficient of variation, $cv(\ln w_{jt}) = \frac{\sigma(\ln w_{jt})}{E(\ln w_{jt})}$, as a function of the share of exporters. The solid line is the quadratic fit that minimizes the total sum of squared errors of the following optimization

$$\min_{c^{cv},\alpha^{cv},\beta^{cv}}\left[\sum_{j,t}(cv(\ln w_{jt}) - c^{sd} - \alpha^{sd} expshare_{jt} - \beta^{sd} expshare^2_{jt})^2\right].$$

As predicted by the HIR model, the coefficient of variation of wages within a sub-industry is first rising and then declining with the increase in trade openness.

The observed regularities might be driven by variation of wages across industries and by other

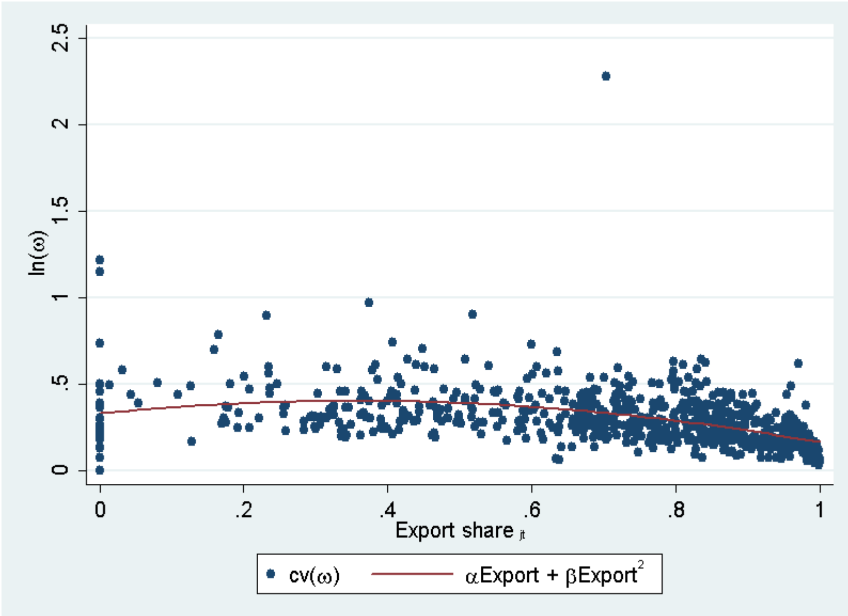

Figure 2: Coefficient of variation and trade openness

factors. To test the predictions on the relationship between sub-industry wage statistics and trade openness, we estimate the following equations

$$\ln w_{jt} = c^m + \eta^m \ln \theta_{jt} + \alpha^m expshare_{jt} + \beta^m expshare^2{}_{jt} + X_{jt}\gamma^m + u_{jt}$$

$$sd(\ln w)_{jt} = c^{sd} + \eta^{sd}\sigma(\ln \theta)_{jt} + \alpha^{sd} expshare_{jt} + \beta^{sd} expshare^2{}_{jt} + X_{jt}\gamma^{sd} + v_{jt}$$

and

$$cv(\ln w)_{jt} = c^{cv} + \eta^{cv}\sigma(\ln \theta)_{jt} + \alpha^{cv} expshare_{jt} + \beta^{cv} expshare^2{}_{jt} + X_{jt}\gamma^{cv} + v_{jt}$$

where $sd(\ln w)_{jt}$ and $cv(\ln w)_{jt}$ are standard deviation and coefficient of variation of wages within the sub-industry j at time t. We estimate these equations with and without sub-industry fixed effects (sub-industry is defined according to 3 digit NACE classification), to explore the relationship within and between industries. The results presented in Panel A of Table 7 indicate that the average wage within sub-industry is positively linked to average productivity, while higher variation of wages within industry is positively linked to variation of productivity. The coefficients of exporter share and exporter share squared have expected signs and are significant in almost all specifications. Overall, we can conclude that the results do not reject the hypothesis on inverse U-shaped relationship between trade openness in the industry and variation of wages.

However, as Panel B of Table 7 indicates, the variation of wages within an industry is mostly explained by the variation in markups, because the coefficient on the variation of productivity becomes insignificant, while the coefficient on the variation of markups is positive and significant.

6 Conclusions

We have studied the impact of firm's technological efficiency and market power on wages. Our empirical analysis was based on a new theoretical model that brings together labor market imperfections, firms' heterogeneity, and variable markups. We have found that the market structure channel plays an important role in shaping the wage distribution within manufacturing industries. Firms with more market power pay higher wages, while the productivity channel is weaker and is not robustly significant. The elasticity of wage with respect to TFP is 0.064, while the elasticity of wage with respect to markup is 0.158 in the baseline specification for the labor productivity. The positive sign of the markup coefficient indicates that the elasticity of aggregate demand is decreasing function of output. This result is robust to the measure of productivity and to the assumptions about the production function.

Firms that increase export to sales by a standard deviation pay a wage premium of 1.4 percent in our baseline IV result based on labor productivity. This channel can be one of the important drivers of the increasing wage gap between high- and low-paid jobs, observed in the last two decades in both developed and developing countries. We also confirm that the effect of the extensive margins of trade on wage inequality has a bell-shaped form, which is consistent with the theoretical model developed by Helpman et al. (2010). From the methodological point, we demonstrate that the OLS estimation of the wage-productivity relationship is biased. The suggested IV approach, which also corrects for the measurement error, allows to eliminate the bias. Finally, based on the industry-level analysis, we find evidence supporting the bell-shaped relationship between the coefficient of variation of wages and the share of exporting firms in the industry.

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Dependent variable	Average wage$_{jt}$		St. Dev. Wage$_{jt}$		Coef. Var. Wage$_{jt}$	
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	FE	OLS	FE	OLS	FE
	A.Without markups					
$\ln \theta_{jt}$	0.055***	0.217***				
	(0.008)	(0.042)				
$\sigma(\ln \theta_{jt})$			0.124***	0.080***	0.042*	0.039*
			(0.026)	(0.023)	(0.017)	(0.019)
Share of exporters$_{jt}$	-0.636**	-0.414	0.577***	0.536***	0.329**	0.240
	(0.234)	(0.228)	(0.092)	(0.101)	(0.112)	(0.122)
Share of exporters$^2_{jt}$	0.594**	0.359	-0.587***	-0.526***	-0.352***	-0.268*
	(0.227)	(0.205)	(0.087)	(0.092)	(0.102)	(0.112)
Share of importers$_{jt}$	-0.023	0.185	0.112*	0.134**	0.027	0.015
	(0.105)	(0.104)	(0.044)	(0.049)	(0.043)	(0.053)
Share of foreign$_{jt}$	0.776***	0.522***	0.156***	0.169***	-0.007	-0.016
	(0.099)	(0.085)	(0.033)	(0.037)	(0.022)	(0.029)
$\ln(L_{jt})$	0.095***	0.055**	-0.054***	-0.066***	-0.045***	-0.044***
	(0.017)	(0.018)	(0.008)	(0.009)	(0.006)	(0.008)
Share of exiting firms$_{jt}$	-1.014***	-0.849**	0.118	0.122	0.367	0.331
	(0.224)	(0.265)	(0.158)	(0.152)	(0.218)	(0.225)
Share of urban$_{jt}$	0.140	0.162	0.010	0.175***	-0.008	0.093
	(0.076)	(0.093)	(0.032)	(0.047)	(0.024)	(0.047)
Sub-Industry FE	No	Yes	No	Yes	No	Yes
Observations	719	719	719	719	719	719
R^2	0.351	0.551	0.323	0.487	0.309	0.355
	B. Including markups					
$\ln \theta_{jt}$	0.055***	0.343***				
	(0.008)	(0.043)				
$\sigma(\ln \theta_{jt})$			0.056	0.014	-0.052	-0.058
			(0.036)	(0.032)	(0.044)	(0.045)
$\ln m_{jt}$	0.034	-0.167***				
	(0.025)	(0.033)				
$\sigma(\ln m_{jt})$			0.106**	0.107**	0.148**	0.157**
			(0.037)	(0.035)	(0.053)	(0.058)
Share of exporters$_{jt}$	-0.668**	-0.356	0.518***	0.439***	0.247*	0.098
	(0.240)	(0.220)	(0.091)	(0.098)	(0.100)	(0.109)
Share of exporters$^2_{jt}$	0.650**	0.264	-0.499***	-0.419***	-0.230*	-0.111
	(0.231)	(0.198)	(0.085)	(0.089)	(0.092)	(0.101)
Share of importers$_{jt}$	-0.065	0.373***	0.082	0.095*	-0.015	-0.042
	(0.105)	(0.096)	(0.043)	(0.046)	(0.038)	(0.041)
Share of foreign$_{jt}$	0.759***	0.521***	0.158***	0.170***	-0.006	-0.016
	(0.099)	(0.082)	(0.032)	(0.037)	(0.020)	(0.026)
$\ln(L_{jt})$	0.098***	0.032	-0.048***	-0.055***	-0.037***	-0.027***
	(0.016)	(0.018)	(0.008)	(0.009)	(0.006)	(0.007)
Share of exiting firms$_{jt}$	-1.052***	-0.700**	0.025	0.044	0.238	0.215
	(0.233)	(0.219)	(0.127)	(0.126)	(0.145)	(0.152)
Share of urban$_{jt}$	0.135	0.144	-0.002	0.161***	-0.024	0.071*
	(0.076)	(0.091)	(0.031)	(0.042)	(0.022)	(0.036)
Sub-Industry FE	No	Yes	No	Yes	No	Yes
Observations	719	719	719	719	719	719
R^2	0.354	0.578	0.358	0.519	0.405	0.452

Standard errors clustered by industries in parentheses. * p<0.05, ** p<0.01, *** p<0.001

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Appendix

Appendix 1. Mathematical proofs

Derivation of (14).

Multiplying both sides of (13) by h yields

$$h\frac{\partial R}{\partial h} = 2wh + \frac{\partial w}{\partial h}h^2 = \frac{\partial}{\partial h}\left(wh^2\right).$$

Integrating across $[0, h]$ and applying integration by parts, we obtain

$$w = \frac{1}{h^2}\int_0^h \frac{\partial R}{\partial \xi}\xi \mathrm{d}\xi = \frac{R(h,\theta,\bar{a})}{h} - \frac{1}{h^2}\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi. \tag{48}$$

Multiplying both sides by h, we come to (14). Q.E.D.

Proof of Claim 1. Differentiating (48) in h, we get

$$\frac{\partial w}{\partial h} = \frac{1}{h^2}\left[h\frac{\partial R}{\partial h} - 2R(h,\theta,\bar{a}) + \frac{2}{h}\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi\right] = \frac{\partial^2}{\partial h^2}\left[\frac{1}{h}\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi\right]. \tag{49}$$

It remains to prove that *revenue* $R(h,\theta,\bar{a})$ *is concave in* h *if and only if* $\frac{1}{h}\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi$ *is concave in* h.

To prove the "if" part, we assume that $R(h,\theta,\bar{a})$ is concave in h. Then, by Jensen's inequality, for any $\alpha\in[0,1]$ and for any $h_1,h_2>0$ we have

$$\frac{1}{m}\sum_{j=1}^{m}R\left(\frac{j}{m}\left(\alpha h_1+(1-\alpha)h_2\right),\theta,\bar{a}\right)\geq\frac{\alpha}{m}\sum_{j=1}^{m}R\left(\frac{jh_1}{m},\theta,\bar{a}\right)+\frac{1-\alpha}{m}\sum_{j=1}^{m}R\left(\frac{jh_2}{m},\theta,\bar{a}\right). \quad (50)$$

Under $m\to\infty$, (50) becomes

$$\frac{1}{\alpha h_1+(1-\alpha)h_2}\int_0^{\alpha h_1+(1-\alpha)h_2}R(\xi,\theta,\bar{a})\mathrm{d}\xi\geq\frac{\alpha}{h_1}\int_0^{h_1}R(\xi,\theta,\bar{a})\mathrm{d}\xi+\frac{1-\alpha}{h_2}\int_0^{h_2}R(\xi,\theta,\bar{a})\mathrm{d}\xi,$$

which means that $\frac{1}{h}\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi$ is concave. This completes the proof of the "if" part.

As for the "only if" part, we prove it by reductio ad absurdum. Namely, assume that $\frac{1}{h}\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi$ is concave in h, while $R(h,\theta,\bar{a})$ is not. Then, it must be that $R(h,\theta,\bar{a})$ is strictly convex in h over some non-degenerate segment $[\underline{h},\overline{h}]$. This implies that if we choose $h_1,h_2\in[\underline{h},\overline{h}]$, the opposite of (50) holds. Consequently, when $m\to\infty$, we have

$$\frac{1}{\alpha h_1+(1-\alpha)h_2}\int_0^{\alpha h_1+(1-\alpha)h_2}R(\xi,\theta,\bar{a})\mathrm{d}\xi<\frac{\alpha}{h_1}\int_0^{h_1}R(\xi,\theta,\bar{a})\mathrm{d}\xi+\frac{1-\alpha}{h_2}\int_0^{h_2}R(\xi,\theta,\bar{a})\mathrm{d}\xi.$$

This, however, violates the assumption that $\frac{1}{h}\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi$ is concave. Thus, we come to a contradiction, and the "only if" part is proven.

Using (49), we conclude that $\partial w/\partial h$ has the same sign as $\partial^2 R/\partial h^2$, which implies Claim 1. Q.E.D.

Derivation of (17). Differentiating (16) with respect to h yields

$$\frac{\partial\beta}{\partial h}=\frac{\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi}{h^2R(h,\theta,\bar{a})}\left[\frac{hR(h,\theta,\bar{a})-\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi}{\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi}-\frac{\partial R(h,\theta,\bar{a})}{\partial h}\frac{h}{R(h,\theta,\bar{a})}\right].$$

Combining this with (16) and using integration by parts, we obtain

$$\mathcal{E}_h(\beta)=\frac{hR(h,\theta,\bar{a})-\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi}{\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi}-\mathcal{E}_h(R)=\frac{\int_0^h \xi\cdot\left[\partial R(\xi,\theta,\bar{a})/\partial\xi\right]\mathrm{d}\xi}{\int_0^h R(\xi,\theta,\bar{a})\mathrm{d}\xi}-\mathcal{E}_h(R).$$

Since $\xi \cdot [\partial R(\xi, \theta, \bar{a})/\partial \xi] = \mathcal{E}_\xi(R) R(\xi, \theta, \bar{a})$, we come to (17). Q.E.D.

Appendix 2. Mapping EBRD indices to services sub-sectors

For four services sub-sectors – Transport, Telecom, Finance, and Other business-related services (hotels and restaurants, real estate, rent, informatization, R&D, agencies) – we map the sub-sector with EBRD indices of reforms as follows:

I: Transportation 1/2(rail + roads)

I1: Telecom (telecom)

J: Finance 1/2(banking + financial)

H+K: Other business-related services (hotels and restaurants, real estate, rent, informatization, R&D, agencies) 1/5(small scale privatization + price liberalization + trade liberalization+ competition reform+ financial reform)