



Contract manufacturing, market competition, and labor productivity in US manufacturing industries

Dazhong Wu¹ · Michael Tannen¹ · Julius Anyu¹ · Sergey Ivanov¹ · Feng Xu¹

Received: 12 February 2022 / Revised: 20 July 2022 / Accepted: 7 August 2022 / Published online: 26 August 2022
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2022

Abstract

How does contract manufacturing /outsourcing affect productivity? Existing studies have conflicting empirical findings regarding this issue. This paper aims to reconcile these conflicting findings in the literature by viewing the research question through the lens of the property rights theory. The authors develop a moderated moderation model to empirically examine how productivity is influenced by the interactions among contract manufacturing, competition, and suppliers' productivity spillover. Our model shows that though conflicting findings have been reported in the literature, each finding holds true under certain conditions which are identified in our paper. In brief, contract manufacturing /outsourcing improves productivity when suppliers' productivity growth is above average and focal industry's competition is at medium level. On the other hand, if suppliers' productivity growth is low, or focal industry's competition is too high or too low, the impact of contract manufacturing /outsourcing could be negative or not significant.

Keywords Contract manufacturing · Productivity spillover · Competition · Outsourcing

1 Introduction

Contract manufacturing is a supply chain arrangement where a manufacturer outsources at least some of its production processes to independent suppliers rather than undertaking those processes in-house (Han et al. 2012; Strange and Magnani 2017; Kim and Schoenherr 2018). Published researches summarized the benefits of contract manufacturing such as cost reductions, better delivery quality, improved valued-added services, and less fixed capital costs (Schilling and Steensma 2001; Broedner et al. 2009; Han et al. 2012).

Though contract manufacturing is often treated interchangeably with manufacturing outsourcing (Han et al. 2012), there exist distinguishing differences between them (Chan and Chung 2002). More specifically, compared with manufacturing outsourcing, contract manufacturing is characterized as long-term relationship rather than arm-length transaction, suppliers managing themselves rather than being managed for performance, and top management rather than purchasing department working with other partners. In

this paper, following Chan and Chung (2002) and Han and Porterfield (2012), we define contract manufacturing as a form of outsourcing arrangement between arm of length market transaction and strategic alliance between vertical partners.

There are essentially two research strands on contract manufacturing. The first line of research is concerned with the factors that influence the choice of contract manufacturing. For example, based on Porter's five-force model and value-chain analysis theories, Han and Porterfield (2012) find that contract manufacturing is positively associated with supplier industry's competition level, and this positive association is moderated by focal industry's competition and its IT investment. Besides, Cheng et al. (2014) show that the level of contract manufacturing is positively associated with supply-side heterogeneity and scale economies, and is negatively associated with concentration levels in the focal and downstream industries.

The second strand studies the impact of contract manufacturing on operational and financial performance. For example, Cheng (2011) studies the impact of contract manufacturing in the US manufacturing industries. It is found that contract manufacturing has a positive impact on product varieties, capital utilization, ROI, and ROA. Cheng et al. (2012) find that contract manufacturing

✉ Dazhong Wu
dazhong.wu@udc.edu

¹ School of Business and Public Administration, University of the District of Columbia, Washington, DC, USA

improves inventory efficiency. However, the impact of contract manufacturing on productivity, which is a more comprehensive measure of performance, has not been studied in the literature. This is the focus of our study.

In this paper, we study how manufacturing industries' productivity improvements are influenced by their contract manufacturing decisions. Based on data of 64 manufacturing industries in a 10-year period (2009–2018), we obtain the following two major findings.

First, contract manufacturing influences productivity through its moderating impact on productivity spillover from suppliers. It is found that when competition level is medium, this moderating impact is positive and significant. This indicates that in a moderately competitive environment, higher contract manufacturing is associated with higher benefits from suppliers' productivity improvement. On the other hand, when competition is too high or too low, this moderating impact is not significant.

Second, contract manufacturing has different impacts on productivity in different environments. This paper identifies the conditions under which contract manufacturing has positive, negative, or no impact on productivity.

This paper contributes to the supply chain management literature in several ways. First, while the literature on contract manufacturing has found a positive connection between contract manufacturing and inventory performance (Cheng et al. 2012), no empirical work has been done to study the impact of contract manufacturing on the productivity, which is a more comprehensive measure of manufacturers' performance.

Second, this study contributes to the outsourcing literature both theoretically and methodologically. Although there is a strand in the outsourcing literature that studies how outsourcing decisions affect productivities, empirical findings in this strand are inconclusive. Researchers find positive relationship (Girma and Görg 2004; Görg et al. 2008; Amiti and Wei 2009; Hijzen et al. 2010; Arvanitis and Loukis 2013; Kar and Dutta 2018; Maziarczyk 2020), negative relationship (Kotabe and Mol 2009; Broedner et al. 2009; Lee et al. 2019; Mazzola et al. 2019), and no statistical significant relationship (Jiang et al. 2006; Capolupo et al. 2017).

For example, Girma and Görg (2004) studied UK manufacturing establishments and found a positive relationship between labor productivity/multi-factor productivity and outsourcing in chemical and mechanical industries but not in electronics industries. Kotabe and Mol (2009) studied Dutch manufacturing companies and found a negative curvilinear relationship between outsourcing and return on value-added. Görg et al. (2008) investigated the impact of outsourcing on Irish manufacturing industries and they found a positive impact. Broedner et al. (2009) found that outsourcing in the Germany manufacturing industries

strongly negatively correlates with labor productivity because outsourcing reduces revenues or increases expenses.

We contribute to the outsourcing literature both theoretically and methodologically. First, unlike other empirical studies in the literature that are primarily based on the transaction cost economics (TCE) or resource based view (RBV), we ground our hypotheses from the lens of the property rights theory, which is mainly used in analytical models in operations management (Tsay et al. 2018). As discussed later, our empirical findings provide strong support in favor of the property rights theory. This sheds light on the outsourcing literature as it highlights the importance of going beyond ECE and RBV, and viewing the impact of outsourcing from multiple theoretical lenses (Lahiri 2016).

Second, existing empirical works in the literature use simple models based on the assumption that the impact of outsourcing on productivity is either constant or linear. We contribute to the literature by presenting a more sophisticated model, which includes contract manufacturing, competition, suppliers' technology improvements, and their interactions. As a result, our paper extends our understandings in the literature because it moves the literature to a more nuanced and complex model that is closer to the reality.

Finally, our empirical results reconcile the conflicting findings in the literature. As illustrated earlier, previous papers have found positive, negative, and no impacts regarding how outsourcing affects productivity. As will be explained later, our model finds that each of the three impacts is just a special case in our model under certain conditions. Our model also identifies the conditions under which each special case holds true. This implies that previous studies took a partial view of a much larger picture. Therefore, our study contributes to the literature by presenting a more comprehensive view of how outsourcing affects productivity.

The remainder of this paper is structured as what follows. Section 2 provides our theoretical basis and the hypotheses of the study. Section 3 details our data collection and variable definitions. In Sect. 4, we build our models and discuss findings from empirical data analysis. Finally, Sect. 5 concludes this study.

2 Theory and hypotheses development

Industries in a supply network are connected rather than isolated from each other. Industries get benefit from their supplier industries' productivity improvement through knowledge spillover and improved quality of parts or services (Swink and Nair 2007; Azadegan and Dooley 2010). As a result, one industry's productivity growth may propagate through supply network and influence its customer industries' productivities. The literature showed strong evidence

of productivity spillovers from supplier industries (Wolff et al. 1993; Smarzynska Javorcik 2004; Paz 2014; Fatima 2016; Stojčić and Orlić 2020). For example, using US input–output data for years 1958–1987, Wolff et al. (1993) found that a focal industry's productivity growth is positively and significantly related to the productivity performance of its supplier industries.

Hypothesis 1 Supplier's productivity growth is positively associated with focal industry's productivity.

In this study, we propose that contract manufacturing moderates the impact of supplier industries' productivity on the focal industry's productivity. We build this hypothesis on the property rights theory, which emphasizes that ownership matters (Grossman and Hart 1986; Hart and Moore 1990). According to the theory, the vertical boundary of a firm determines the ex-ante investment incentives of different parties involved. Figure 1 illustrates the idea.

The figure shows two scenarios. In scenario (A), firm i performs backward integration with a division (i.e., division j) operating in the supplier industry. In scenario (B), firm i unbundles its supply chain and outsources the production of parts to an independent firm (i.e., firm j) through contract manufacturing.

According to the property rights theory, firm j in scenario (B) may have higher incentive to invest to improve the quality of its products compared with division j in scenario (A). The reason is that backward integration in scenario (A) may reduce the investment incentive of division j, as division j does not own assets and is therefore subject to hold-up problem (Gibbons 2005). This idea is based on the property rights theory and has been verified by previous analytical and empirical studies. For example, Acemoglu et al. (2010)

found that backward vertical integration (as in scenario (A)) is negatively and significantly associated with investment incentive in R&D of suppliers (i.e., upstream divisions such as division j).

As a result, contract manufacturing preserves the suppliers' incentives to make investment to increase productivity, and therefore, increases the benefit a focal firm may receive from its supplier industries' productivity improvement.

Hypothesis 2 The impact of supplier industry's productivity on the focal industry's productivity increases with contract manufacturing.

Though in general contract manufacturing has a positive moderating impact on the effect of suppliers' productivity, this moderating effect is influenced by the competition level in the focal industry. More specifically, competition has two conflicting impacts on contract manufacturing's moderating effects.

On the one hand, an increase in focal industry's competition has a positive impact on contract manufacturing's moderating effect for three reasons. First, manufactures' competition increases suppliers' incentive to innovate and invest on relationship-specific assets. When focal industry is dominated by only a few manufactures, suppliers have low bargaining power and are subject to hold up problem. As a result, suppliers have low incentive to innovate and invest in relationship-specific assets. An increase in competition increases suppliers' bargaining power and reduces their fear of hold up problems (Gibbons 2005), and therefore increases their incentive to innovate. Second, competition reduces manufacturer's asset specialty and therefore reduces transaction cost (Aghion et al. 2006). Finally, competition may increase manufacturers' incentive to innovate to take advantage of suppliers' productivity improvements.

On the other hand, an increase in focal industry's competition has a negative impact on contract manufacturing's moderating effect. As competition reduces focal industry's bargaining power and increases suppliers' capability to appropriate a larger share of quasi-rents, thereby reducing the benefit of contract manufacturing.

When focal industry's competition level is low, small increase in competition does not change the focal industry's bargaining position, instead it increases suppliers' incentive to innovate (Aghion et al. 2006). So, the positive impact dominates the negative impact. In such a situation, an increase in competition increases the moderating impact of contract manufacturing on productivity spillover from suppliers. However, when focal industry's competition level is increased above a certain level, suppliers have enough bargaining power and therefore hold up problem is no longer a big concern for them. In this situation, the negative impact dominates the positive impact, because an increase in

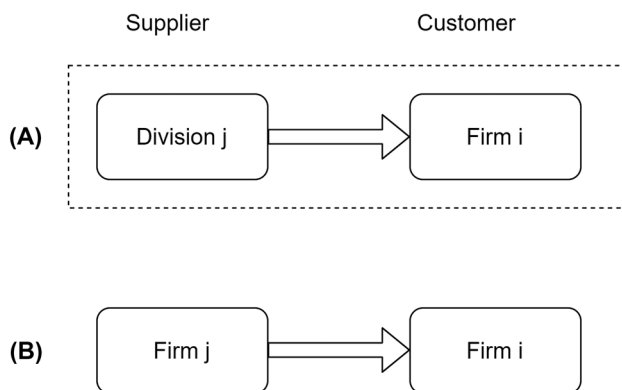


Fig. 1 An illustration of firm boundaries. In sub-figure (A), firm i performs backward integration with a division (i.e., division j) operating in the supplier industry. In sub-figure (B), firm i unbundles its supply chain and outsources the production of parts to an independent firm (i.e., firm j) through contract manufacturing

competition doesn't significantly affect the suppliers' incentive issue as discussed earlier, however, it will dramatically increase the likelihood of suppliers' opportunistic behavior in contract manufacturing setting, thereby reducing contract manufacturing's positive moderating effect. Therefore, we hypothesize that there is a reversed u-shaped relationship between competition and contract manufacturing's moderating effect.

Hypothesis 3 Contract manufacturing's moderating effect (as in Hypothesis 2) is higher when competition is at a medium level than when it is at a very high or very low level.

Figure 2 shows the variables involved in the hypotheses and their relationships. Note that in the figure dashed links represent moderating effects.

3 Data and variables

3.1 Data

Following previous literature on contract manufacturing (Schilling and Steensma 2001; Han et al. 2012; Cheng et al. 2012, 2014), we collect data at the industry level from the sources below:

1. The annual survey of manufactures by US Census Bureau
2. Input–output tables by Bureau of Labor Statistics
3. Labor productivity data by Bureau of Labor Statistics
4. Industry concentration data by US Census Bureau
5. Patent data from United States Patent and Trademark Office

The Annual Survey of Manufactures reports financial and operational data such as labor cost, cost of materials, capital expenditures, shipments, inventory, expenditure on

contract work, IT investment, and so on. Since this survey covers all manufacturing establishments with at least one paid employee, it provides a very comprehensive view of the US manufacturing industries.

We obtained annual USE matrix from BLS (Bureau of Labor Statistics) input–output tables. The USE matrix contains data on the value of products from every supplier industry consumed by every customer industry.

For years ending in 2 and 7 (e.g., year 2007 or 2012), US Census Bureau reports manufacturing industries' concentration levels measures by their HHI (Hirshman Herfindalh Index) values which range between 0 and 1. We choose the data in year 2012 as it is the only one within the period of our study. As of December 2021, the concentration data for year 2017 has not been released yet.

These data sources report industries at different detail levels. BLS input–output include industries at 4-digit NAICS levels, while other sources report industries at 4- to 6-digit NAICS levels. After we match data from these sources, we calculate variables used in our models, as described next. Finally, we have a panel of 584 observations that involve 64 manufacturing industries at the 4-digit NAICS level in 10 years (2009–2018).

3.2 Measures of variables

3.2.1 Dependent variable

Our dependent variable is growth in labor productivity, which is directly obtained from BLS. According to BLS (2017), the growth in labor productivity in year t is calculated as:

$$Y_t = \frac{Q_t}{Q_{t-1}} \frac{L_t}{L_{t-1}} - 1$$

where Q is revenue deflated by price index, L is total hours worked.

3.2.2 Independent variables

Contract manufacturing Previous literature (Han et al. 2012; Cheng et al. 2012, 2014) measures contract manufacturing for each industry as its expenditure on contract work divided by its total cost of materials. However, the calculated contract manufacturing ratio is highly skewed to the right (skewness = 1.6). Therefore, we take natural log of it, which reduces its skewness to 0.15.

Competition Following the competition literature (Giroud and Mueller 2010; Han et al. 2012; Mubeen et al. 2020), we use industry concentration to proxy for competition. According to the literature, a high (low) industry concentration

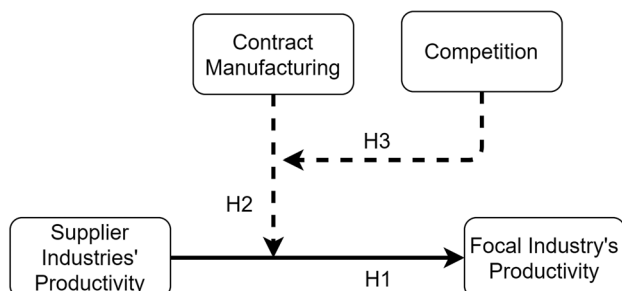


Fig. 2 Hypotheses. Note that in the figure dashed links represent moderating effects

value indicates a low (high) competition environment. A commonly used measure of industry concentration is Hirshman Herfindalh Index (Golan et al. 1996).

We first collect industry Hirshman Herfindalh Index (HHI) data from US Census Bureau. We then follow Giroud and Mueller (2010) and Rakestraw (2020) by sorting industries into three groups (i.e., bottom one third for low concentration, middle one third for medium concentration, and top one third for high concentration) based on their HHIs. Finally, we generate three dummy variables to reflect industries' competition levels. More specifically, H is the dummy variable equal to one if the focal industry is in the high competition (i.e., low concentration) group. Similarly, L (low competition) and M (medium competition) are the dummy variables equal to one for industries in the high and middle concentration groups respectively.

Suppliers' productivity growth For focal industry i , its supplier productivity growth in year t is the weighted average of its suppliers' productivity growth (Wolff et al. 1993):

$$S_{it} = \sum_{j \neq i} \frac{U_{jit} Y_{jt}}{\sum_{k \neq i} U_{kit}}$$

In the equation above, Y_{jt} is the productivity growth of supplier industry j in year t . U_{jit} is the value of products provided by industry j and consumed by the focal industry. $\sum_{k \neq i} U_{kit}$ is the total purchase of the focal industry from its supplier industries. So, $U_{jit}/(\sum_{k \neq i} U_{kit})$ indicates the importance level of supplier industry j to the focal industry as a supplier.

3.2.3 Control variables

Innovation Following the innovation literature, we date patents using their application years and then use the count of patents granted to each industry as a proxy for industry innovation. When matching patent data with industry-level data, we follow the literature (Consoli et al. 2016; Lechner et al. 2016; Levine et al. 2017) and use the concordance from the International Patent Classification (IPC) to the 4-digit NAICS provided by Lybbert and Zolas (2014). Finally, for each industry in each year we calculate its innovation growth as $P_{it}/P_{i,t-1} - 1$, where P_{it} is the count of patents granted to industry i within application year t .

Unionization We control for increase rate of unionization in the model as it may influence manufacturers' decisions to outsource and therefore the impact

of outsourcing/contract manufacturing (Kotabe et al. 2007). Unionization is defined as union membership divided by total employment (Han et al. 2012) in each industry. We obtained the corresponding data from Union Membership and Coverage Database (Hirsch and Macpherson 2003).

Market growth and uncertainty We also control for each industry's growth rate and demand uncertainty in the model. More specifically, we follow Keats and Hitt (1988) and ran the following regression:

$$\ln(Y_{it}) = a + b \cdot t$$

where Y_{it} is the sales of industry i in year t . For each industry in each year, we run regression based on the industry's annual sales in the past 5 years. Growth rate is the estimate of the regression slope b and demand uncertainty is the standard error of b .

Growths of material input and capital intensity We follow the literature (e.g., Girma and Görg 2004; Amiti and Wei 2009) and include annual growth rates of material input and of capital intensity as control variables. Both variables are directly from the labor productivity dataset from Bureau of Labor Statistics.

Table 1 summarizes the variables in their original values and their correlations in their original.

As shown in the table, average contract manufacturing is around 3% of total material purchase, which is consistent with prior studies (e.g., Han et al. 2012; Cheng et al. 2012). Labor productivity growth, the dependent variable, is significantly correlated with three independent variables: suppliers productivity growth, innovation, and material input growth. However, only regression can tell which independent variables have significant impacts.

On the other hand, we see some significant correlations among independent variables. For example, contract manufacturing has strong and negative correlations with concentration (HHI), and union rate. These strong correlations among independent variables raise the concern of multi-collinearity issue in our model. Therefore, we calculate VIF (variance inflation factor) for each independent variable and each is well below 5. This indicates that multi-collinearity is not an issue in our model (James et al. 2013).

For each dependent variable or independent variable mentioned above, we first winsorize it at levels 2% and 98%, and then standardize it by (1) subtracting its mean from each value and (2) dividing each value by its standard deviation.

Table 1 Variable statistics and correlation matrix

Statistic	Mean	St. Dev.	Min	Max	1	2	3	4	5	6	7	8	9	10
1. Labor Productivity Growth (%) Y_{it}	0.2	6.8	-32.2	29.8	1									
2. Contract Manufacturing	0.03	0.03	0.002	0.1	0.03	1								
3. Contract Manufacturing (natural log) $C_{i,t-1}$	-4	0.9	-6.5	-1.9	0.02	0.88*	1							
4. Suppliers' Productivity Growth (%) S_{it}	0.6	4.3	-17.9	26.1	0.21*	-0.02	-0.02	1						
5. Concentration (HHI)	378.9	428	7.5	2,896.70	0.05	-0.13*	-0.18*	0.02	1					
6. Innovation	0.02	0.1	-0.6	0.4	0.14*	-0.04	-0.06	0.15*	0.14*	1				
7. Market Growth	0.003	0.1	-0.3	0.1	0.02	-0.06	-0.14*	-0.09*	0.01	0.12*	1			
8. Market Uncertainty	0.02	0.02	0	0.1	0.02	0.06	0.13*	0	-0.05	0.06	-0.31*	1		
9. Union Rate	0.1	0.1	0	0.3	0.04	-0.15*	-0.22*	-0.03	0.23*	0	0.09*	0.17*	1	
10. Material Input Growth (%)	0.2	9.1	-48.8	41	0.5*	-0.04	-0.06	0.24*	0.01	0.23*	0.29*	-0.09*	0.02	1
11. Capital Intensity Growth (%)	0.2	7.2	-19.7	36.3	0.05	0.05	0.05	-0.34*	0.08*	-0.19*	-0.15*	0.11*	0.04	-0.54*

In the first 5 columns, this table reports descriptive statistics (mean, standard deviation, min, and max values) of each variable used in the model. Correlation matrix of these variables starts from column 6

* p -value ≤ 0.05

4 Model and results

4.1 Model specification

The panel data model is specified in Eq. (1). As the symbols used in the equation will be extensively presented in the subsequent sections, we summarize these symbols, their meanings, and the sections in which they are discussed in Table 2, for the convenience of readers.

$$\begin{aligned}
 Y_{it} = & \beta_0 + \beta_1 C_{i,t-1} + \beta_2 S_{it} + \beta_3 H_i \\
 & + \beta_4 L_i + \gamma_1 C_{i,t-1} S_{it} H_i \\
 & + \gamma_2 C_{i,t-1} S_{it} L_i + \delta_1 C_{i,t-1} S_{it} \\
 & + \delta_2 C_{i,t-1} H_i + \delta_3 C_{i,t-1} L_i \\
 & + \delta_4 S_{it} H_i + \delta_5 S_{it} L_i + \alpha' Z_{it} \\
 & + \sigma F_i + \rho F_t + \varepsilon_{i,t}
 \end{aligned} \quad (1)$$

In the model, i and t index industry and time respectively. Y_{it} is growth of labor productivity, $C_{i,t-1}$ is the natural log of contract manufacturing, and S_{it} is supplier industries' labor productivity. Note that variable contract manufacturing $C_{i,t-1}$ is lagged by one year to avoid reverse causality.

H_i and L_i are the dummy variables equal to one if the focal industry is in the high competition group and the low competition group respectively, and zero otherwise. Note that there are three variables (H_i , M_i , and L_i) that reflect industry competition levels. Dummy variable M_i is dropped to avoid redundancy. Since we include three-way interactions (i.e., $C_{i,t-1} S_{it} L_i$ and $C_{i,t-1} S_{it} H_i$), we also need to include each two-way interaction term in our model (Aiken and West 1991; Jaccard et al. 2003; Wang et al. 2022).

Z_{it} is a vector of control variables that include innovation, unionization (lagged by one year to avoid reverse causality), growth rate, market uncertainty, material growth, and capital intensity growth. F_i and F_t are industry and year fix effects respectively. Finally, $\varepsilon_{i,t}$ is the error term.

4.2 Regression results

Table 3 shows three models. Model (1) is our base model which doesn't include any interaction term. Model (2) extends the model by including the interaction between contract manufacturing and supplier industries' productivity growth. Model (3) is our full model as in Eq. (1).

In column (1), supplier industries' productivity growth has a positive and significant (at $p=0.05$ level) impact on focal industry's productivity growth. Therefore, Hypothesis 1 is supported.

In column (2), the interaction between supplier industries' productivity growth and contract manufacturing (i.e., δ_1) is positive but not significant. Therefore, Hypothesis 2

Table 2 Notation list

Notation	Description	Section
Y_{it}	Growth of labor productivity	3.2.1
$C_{i,t-1}$	Contract manufacturing (lagged by one year)	3.2.2
S_{it}	Suppliers' labor productivity	3.2.2
H_i	A dummy variable set to 1 if the focal industry is in the high competition tercile	3.2.2
L_i	A dummy variable set to 1 if the focal industry is in the low competition tercile	3.2.2
M_i	A dummy variable set to 1 if the focal industry is in the medium competition tercile	3.2.2
Z_{it}	A vector of control variables	3.2.3
F_i	Industry fixed effect	
F_t	Time fixed effect	

is not supported. However, δ_1 is positive and significant (at $p=0.01$ level) in column (3), indicating that Hypothesis 2 is supported for industries with medium competition levels. Note that δ_1 has different meanings in column (2) and column (3). In column (2), δ_1 represents contract manufacturing's moderating effect on the impact of supplier industries' productivity growth for all industries and is therefore related to Hypothesis 2, while in column (3) δ_1 is the moderating effect for industries in the medium competition group (i.e., $M=1$). More specifically, the moderating effect of contract manufacturing on the impact of supplier industries' productivity growth is:

$$\frac{\partial}{\partial C_{i,t-1}} \left(\frac{\partial Y_{it}}{\partial S_{it}} \right) = \gamma_1 H_i + \gamma_2 L_i + \delta_1$$

$$= \begin{cases} \gamma_1 + \delta_1 & H_i = 1 (\text{high competition}) \\ \gamma_2 + \delta_1 & L_i = 1 (\text{low competition}) \\ \delta_1 & M_i = 1 (\text{medium competition}) \end{cases}$$

In other words, δ_1 represents the moderating effect of contract manufacturing when the focal industry's competition is moderate. Here, γ_1 (or γ_2) is the difference in the moderating effects between the high (or low) competition group and the medium competition group.

In column (3), δ_1 is positive and significant (at $p=0.01$ level), which implies that contract manufacturing's moderating effect is positive and significant for industries in the medium competition group. On the other hand, γ_1 and γ_2 are both negative and significant (at 0.01 and 0.05 level respectively). This means that the moderating effects of contract manufacturing is significantly lower in the high and low competition groups than that in the middle competition group. Therefore, Hypothesis 3 is supported.

Table 4 shows the empirical estimates of contract manufacturing's moderating effect in different competition groups. Note that the estimate for medium competition group is directly from δ_1 in Table 3. For the estimate for high competition group, we run a regression on a model like Eq. (1) but with L_i and M_i included and H_i dropped. The estimate

for low competition group is obtained similarly. As shown in the table, contract manufacturing's moderating effect is positive and significant when competition is medium, but it is not significant in the high or low competition group.

Based on Table 4, we draw in Fig. 3 the estimates of contract manufacturing's moderating effects when competition is in low, medium, and high levels, and their 95% confidence intervals. It is clear from the figure that as competition increases, contract manufacturing's moderating effect first increases and then decreases, indicating a reversed u-shaped relationship between competition and the moderating effect of contract manufacturing.

This result is consistent with Aghion et al. (2006) who found a u-shaped relationship between competition and vertical integration: when competition level is low, an increase in competition reduces firms' vertical integration; but when competition level is high, an increase in competition increases firms' incentive to become more vertically integrated.

4.3 Productivity spillover from suppliers

From Eq. (1), the impact of suppliers' productivity growth on focal industry's productivity is

$$\frac{\partial Y_{it}}{\partial S_{it}} = \beta_2 + \gamma_1 C_{i,t-1} H_i$$

$$+ \gamma_2 C_{i,t-1} L_i + \delta_1 C_{i,t-1} + \delta_4 H_i + \delta_5 L_i$$

$$= \begin{cases} \beta_2 + \gamma_1 C_{i,t-1} + \delta_4 & H_i = 1 \\ \beta_2 + \gamma_2 C_{i,t-1} + \delta_5 & L_i = 1 \\ \beta_2 + \delta_1 C_{i,t-1} & M_i = 1 \end{cases}$$

In the equation above, the marginal effect of suppliers' productivity growth on focal industry's productivity growth ($\partial Y_{it} / \partial S_{it}$) is determined by contract manufacturing ($C_{i,t-1}$), and competition levels. We calculate the estimates of $\partial Y_{it} / \partial S_{it}$ as a function of $C_{i,t-1}$ when competition level is low, medium, and high respectively, as well as their 95% confidence intervals. Then we plot $\partial Y_{it} / \partial S_{it}$ in Fig. 4 to

Table 3 Regression results

		(1)	(2)	(3)
Contract Manufacturing	β_1	0.037 (0.022)	0.034 (0.022)	0.056 (0.035)
Suppliers' Productivity	β_2	0.083* (0.035)	0.085* (0.034)	0.169* (0.071)
H	β_3	0.009 (0.046)	0.009 (0.046)	-0.0002 (0.044)
L	β_4	0.050 (0.055)	0.051 (0.055)	0.040 (0.061)
Contract Manufacturing \times Suppliers' Productivity \times H	γ_1			-0.323** (0.115)
Contract Manufacturing \times Suppliers' Productivity \times L	γ_2			-0.207* (0.093)
Contract Manufacturing \times Suppliers' Productivity	δ_1		0.048 (0.035)	0.225** (0.083)
Contract Manufacturing \times H	δ_2			-0.020 (0.058)
Contract Manufacturing \times L	δ_3			-0.034 (0.046)
Suppliers' Productivity \times H	δ_4			0.006 (0.104)
Suppliers' Productivity \times L	δ_5			-0.123 (0.089)
Innovation		0.051 (0.034)	0.052 (0.035)	0.054 (0.034)
Uncertainty		-0.013 (0.033)	-0.015 (0.032)	-0.021 (0.032)
Growth		-0.188*** (0.033)	-0.189*** (0.033)	-0.190*** (0.033)
Unionization		-0.016 (0.029)	-0.016 (0.029)	-0.017 (0.029)
Material Input Growth		0.753*** (0.047)	0.753*** (0.048)	0.743*** (0.048)
Capital Intensity Growth		0.663*** (0.039)	0.660*** (0.039)	0.657*** (0.040)
Constant		0.008 (0.034)	0.007 (0.034)	0.016 (0.037)
Observations		584	584	584
R ²		0.496	0.500	0.517
Adjusted R ²		0.487	0.490	0.502

Robust standard errors in parentheses

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Fig. 6. In those figures, the x axis is contract manufacturing, and the y axis is the marginal impact of suppliers' productivity growth. Labels 25%, 50%, and 75% represent the 25th, 50th, and 75th percentiles of contract manufacturing. Note that for $\partial Y_{it}/\partial S_{it}$ to be significant, the 95%

Table 4 Contract manufacturing's moderating effect in different competitive environments

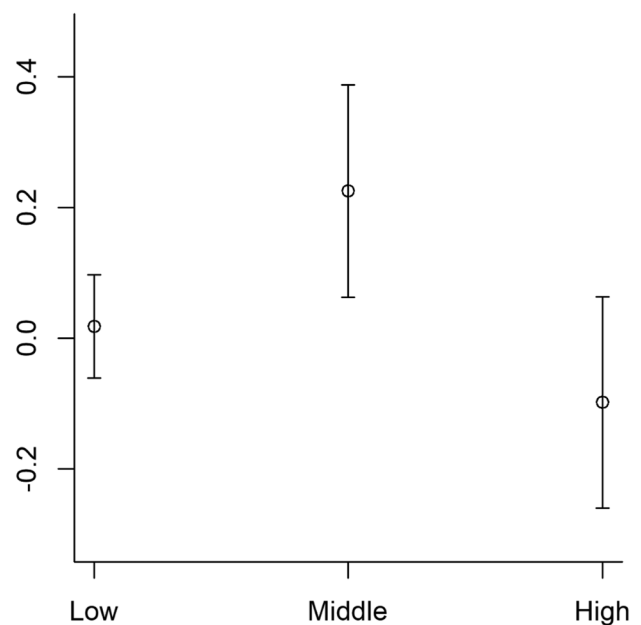
	Coefficient	Robust Std Error
Low competition (L = 1)	0.018	0.040
Medium competition (M = 1)	0.225	0.083**
High competition (H = 1)	-0.098	0.082

** $p < 0.01$

confidence interval should be strictly above or below the x axis. In other words, 0 cannot be included in the 95% confidence interval.

When competition level is low (Fig. 4), $\partial Y_{it}/\partial S_{it} = 0$ is always included in the 95% confidence interval. This indicates that when competition is low, suppliers' productivity growth does not have a significant impact on focal industry's labor productivity. There are many possible reasons. For example, with low competition the focal industry has low incentive to take advantage of suppliers' productivity improvements. Previous studies also find that when competition is low firms are more likely to be vertically integrated (Aghion et al. 2006), which reduces the impact of (external) supplier industries' productivity growth.

When competition is medium (Fig. 5), suppliers' productivity spillover ($\partial Y_{it}/\partial S_{it}$) is initially negative and significant when contract manufacturing is below the third percentile (marked by the first dashed line). This implies that industries with extremely low contract manufacturing do not get benefit from suppliers' productivity growth due to missed

**Fig. 3** Contract manufacturing's moderating effect in different competitive environments

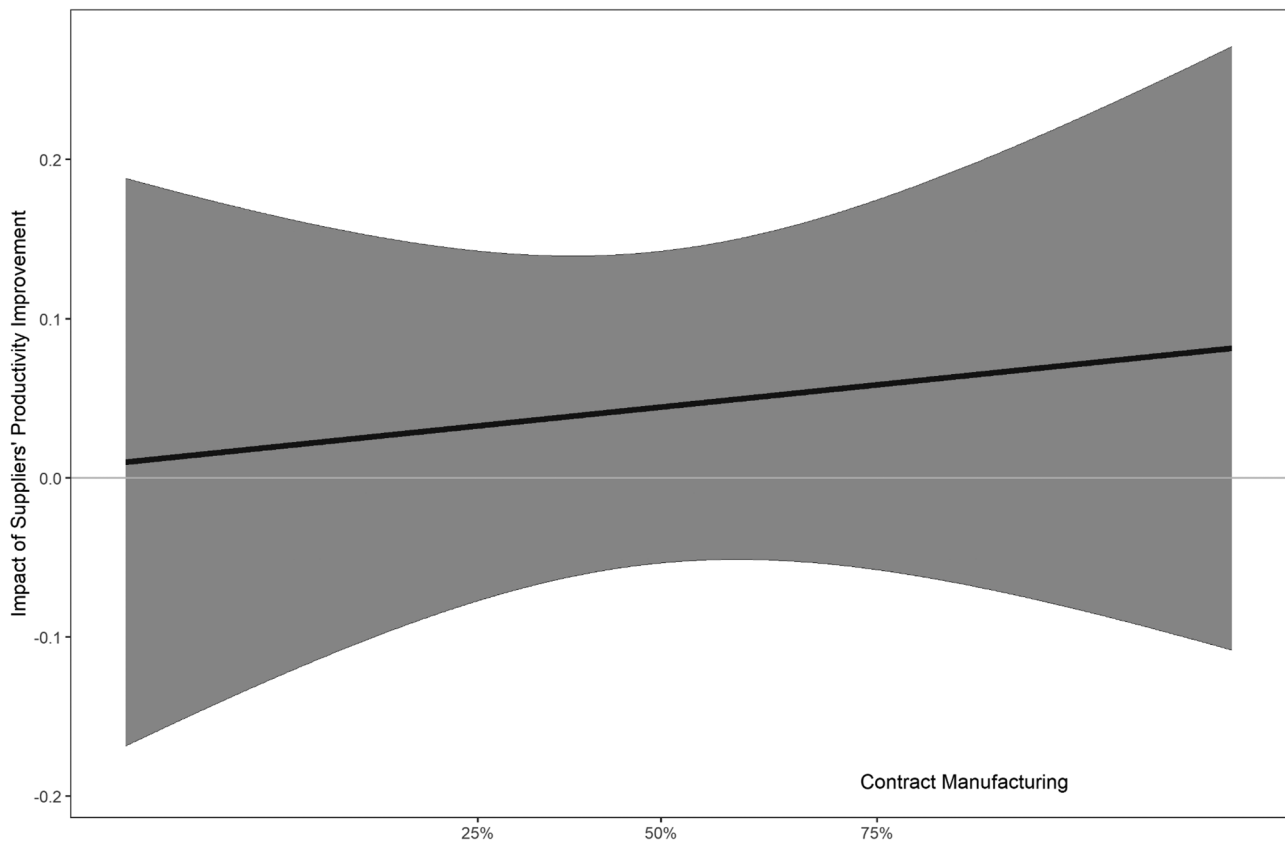


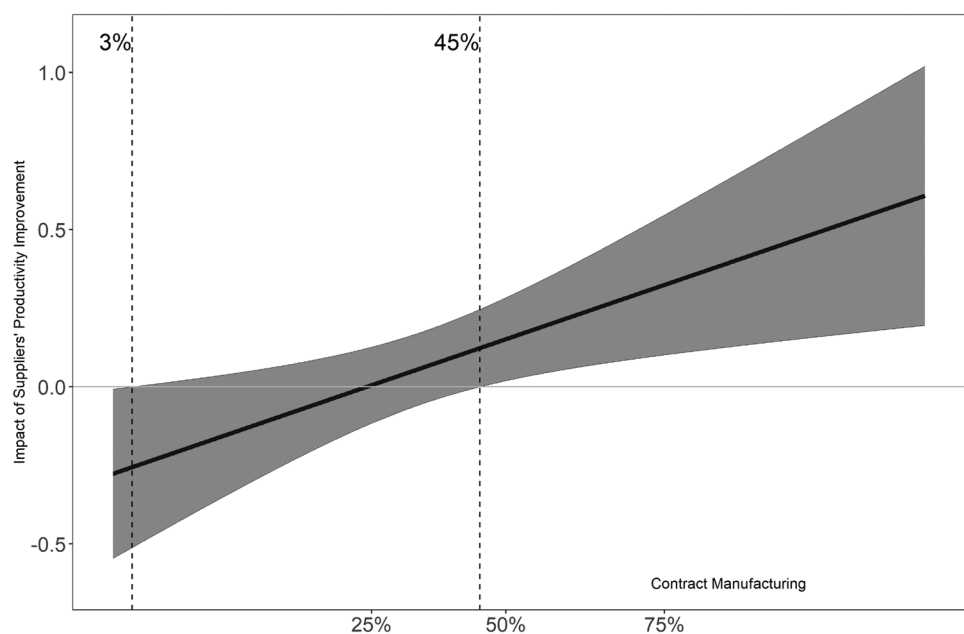
Fig. 4 The impact of suppliers' productivity improvement when competition level is low

opportunity. However, the percentage (i.e., 3%) is too low to be statistically meaningful.

On the other hand, suppliers' productivity spillover ($\partial Y_{it}/\partial S_{it}$) increases with contract manufacturing as

indicated by the upward line. This positive slope (δ_1) is statistically significant at 0.01 level as shown in Table 3. In other words, contract manufacturing increases the benefits received from suppliers. In the figure, when

Fig. 5 The impact of suppliers' productivity improvement when competition level is medium



contract manufacturing is greater than its 45th percentile (indicated by the second dashed line), the 95 percent confidence interval is strictly above the x axis. This indicates that suppliers' productivity growth has a significant and positive impact on focal industry's productivity when the focal industry's contract manufacturing ratio is not too low. On the other hand, when contract manufacturing is between its 3rd percentile and its 45th percentile, productivity spillover from suppliers has no significant impact.

An implication from the increasing line in Fig. 5 is that the greater the suppliers' productivity improvement, the more benefits from contract manufacturing for industries with medium levels of competition. This is consistent with the property rights theory which states that if suppliers' innovation is important to the focal industry's growth, the focal industry needs to outsource the corresponding productions to supplier industries rather than making those parts internally (Acemoglu et al. 2010; Frésard et al. 2020).

When competition level is high (Fig. 6), the estimate of $\partial Y_{it}/\partial S_{it}$ is a downward line. However, this negative slope is not significantly different from zero as shown in Table 4. This implies that contract manufacturing may not have a significant impact on productivity spillover from suppliers. In the figure, $\partial Y_{it}/\partial S_{it}$ is positive and significant when contract manufacturing is between its 24th and 73th percentiles, and non-significant elsewhere. This indicates that when competition level is high, industries still manage to take advantage of suppliers' productivity growth, but not through contract manufacturing.

4.4 Discussion

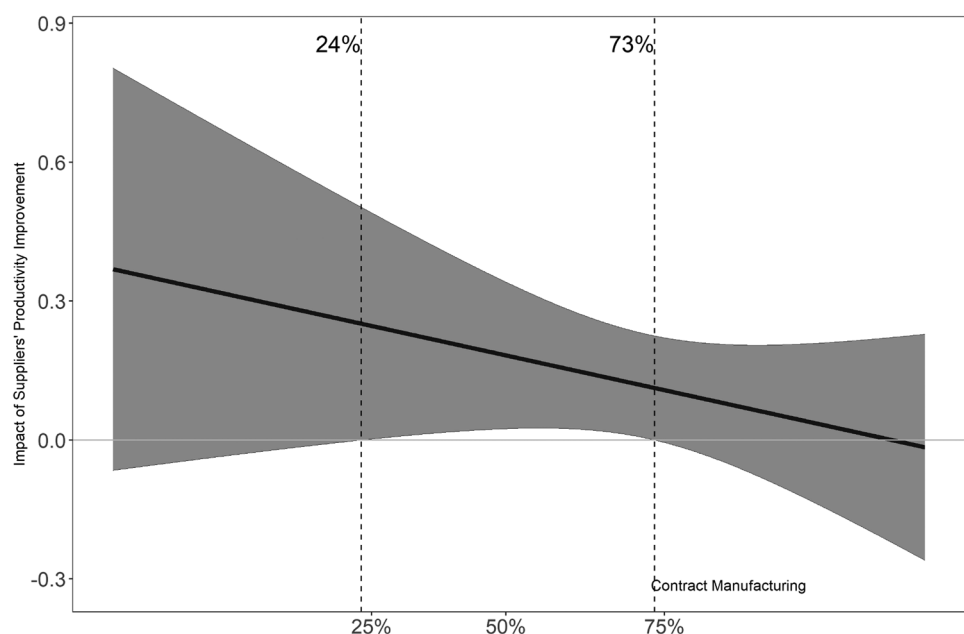
As discussed in Sect. 1, previous studies have reported conflicting findings regarding the impact of outsourcing on productivity. Outsourcing was shown by these studies to have positive, negative, or no impact on productivity. Next, we will show that each of these findings is associated with a partial view of the entire picture. In other words, we will derive the conditions under which contract manufacturing/outsourcing has positive, negative, or no impact on labor productivity.

The calculation and plotting process is similar to that in Sect. 4.3. The only difference is that rather than looking at $\partial Y_{it}/\partial S_{it}$, we examine $\partial Y_{it}/\partial C_{i,t-1}$, the marginal impact of contract manufacturing on labor productivity. From Eq. (1), the impact of contract manufacturing on productivity is

$$\begin{aligned} \frac{\partial Y_{it}}{\partial C_{i,t-1}} &= \beta_1 + \gamma_1 S_{it} H_i \\ &\quad + \gamma_2 S_{it} L_i + \delta_1 S_{it} + \delta_2 H_i + \delta_3 L_i \\ &= \begin{cases} \beta_1 + \gamma_1 S_{it} + \delta_2 H_i = 1 \\ \beta_1 + \gamma_2 S_{it} + \delta_3 L_i = 1 \\ \beta_1 + \delta_1 S_{it} = 1 \end{cases} \end{aligned}$$

Then in Fig. 7 we plot $\partial Y_{it}/\partial C_{i,t-1}$ as a function of S_{it} (i.e., suppliers' productivity growth) when competition level is low, medium, and high respectively, as well as their 95% confidence intervals. In each sub-figure, the x axis is supplier industries' productivity growth, and the y axis represents the marginal impact of contract manufacturing on focal industry's productivity growth. Labels 25%, 50%, and 75% represent the 25th, 50th, and 75th percentiles of suppliers' productivity growth.

Fig. 6 The impact of suppliers' productivity improvement when competition level is high



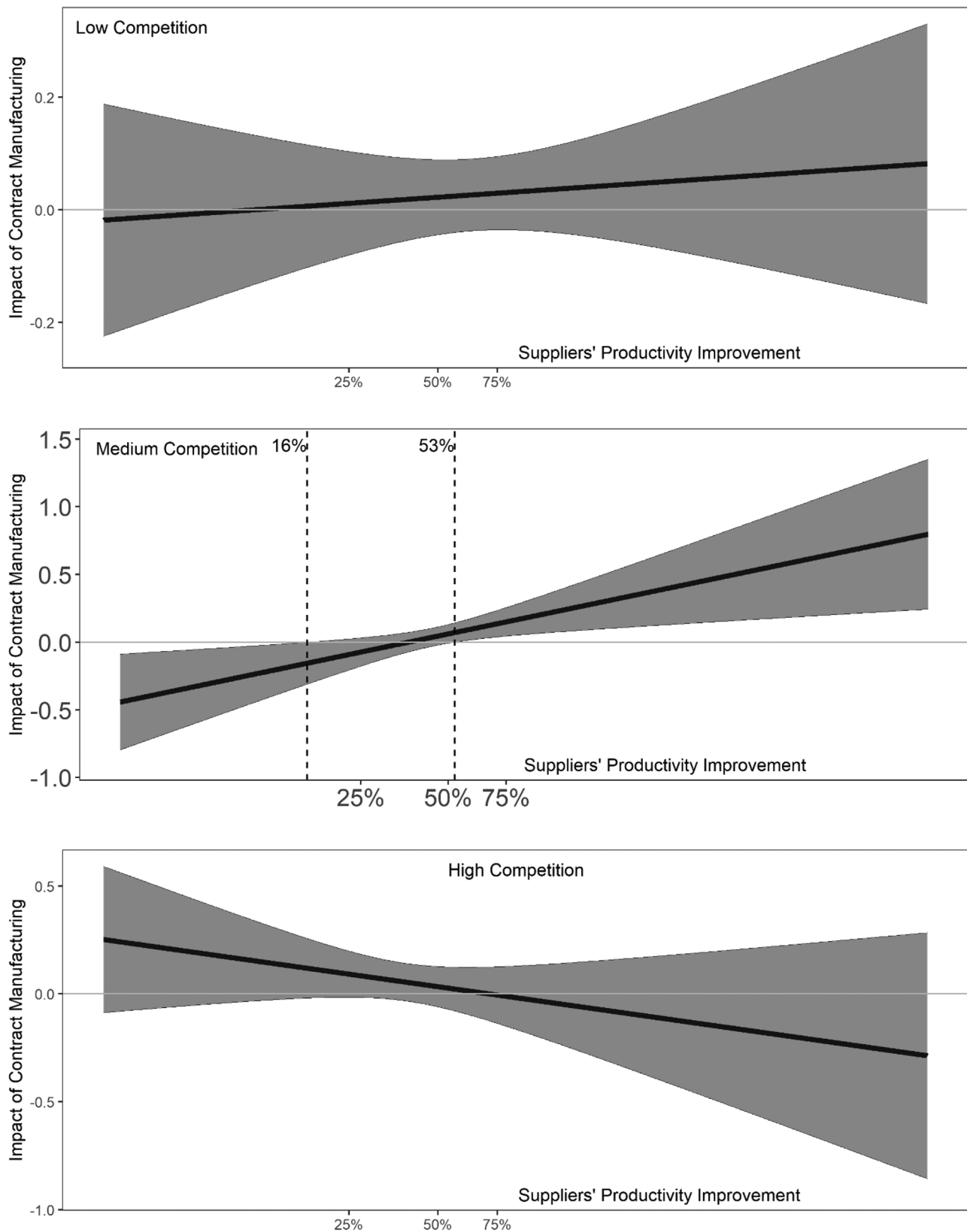


Fig. 7 The impact of contract manufacturing

Table 5 Regression results (alternative measure of concentration)

		(1)	(2)	(3)
Contract Manufacturing	β_1	0.037 (0.022)	0.034 (0.022)	0.056 (0.035)
Suppliers' Productivity	β_2	0.083* (0.035)	0.085* (0.034)	0.169* (0.071)
H	β_3	0.009 (0.046)	0.009 (0.046)	-0.0002 (0.044)
L	β_4	0.050 (0.055)	0.051 (0.055)	0.040 (0.061)
Contract Manufacturing \times Suppliers' Productivity \times H	γ_1			-0.323** (0.115)
Contract Manufacturing \times Suppliers' Productivity \times L	γ_2			-0.207* (0.093)
Contract Manufacturing \times Suppliers' Productivity	δ_1		0.048 (0.035)	0.225** (0.083)
Contract Manufacturing \times H	δ_2			-0.020 (0.058)
Contract Manufacturing \times L	δ_3			-0.034 (0.046)
Suppliers' Productivity \times H	δ_4			0.006 (0.104)
Suppliers' Productivity \times L	δ_5			-0.123 (0.089)
Innovation		0.051 (0.034)	0.052 (0.035)	0.054 (0.034)
Uncertainty		-0.013 (0.033)	-0.015 (0.032)	-0.021 (0.032)
Growth		-0.188*** (0.033)	-0.189*** (0.033)	-0.190*** (0.033)
Unionization		-0.016 (0.029)	-0.016 (0.029)	-0.017 (0.029)
Material Input Growth		0.753*** (0.047)	0.753*** (0.048)	0.743*** (0.048)
Capital Intensity Growth		0.663*** (0.039)	0.660*** (0.039)	0.657*** (0.040)
Constant		0.008 (0.034)	0.007 (0.034)	0.016 (0.037)
Observations		569	569	569
R ²		0.495	0.498	0.513
Adjusted R ²		0.486	0.488	0.497

Robust standard errors in parentheses

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

As shown in the figure, when competition is low (as in the top sub-figure) or high (as in the bottom sub-figure) $\partial Y_{it} / \partial C_{i,t-1} = 0$ is always included in the 95% confidence interval, which means contract manufacturing doesn't have significant impact on labor productivity.

When competition is medium (as in the middle sub-figure), contract manufacturing is negatively associated with productivity when suppliers' productivity growth is less than its 16th percentile. This means that outsourcing to industries that have low productivity improvements may negatively affect focal industry's productivity. On the other hand, in the same sub-figure, contract manufacturing is positively and significantly associated with productivity when suppliers' productivity growth is above its 53rd percentile. This means that the two necessary conditions for contract manufacturing to improve labor productivity are (1) that supplier industries have higher-than-average growth rates in labor productivity and (2) that competition level should be medium.

Figure 7 shows the conditions under which contract manufacturing has positive, negative, or no impact of productivity. To put it in another way, each previous finding in the literatures is a special case in Fig. 7, and our model reconciles previous conflicting findings as it provides a much more comprehensive view of the entire picture.

4.5 Robustness check

We have built and tested our primary model of contract manufacturing and labor productivity. We then assess the robustness of our results.

In our primary model we used Herfindahl–Hirschman Index (HHI) to measure concentration and competition. Another popular measure to serve the same purpose is four-firm concentration ratio which is the total market share of the largest four firms in the industry (Dorn et al. 2017). We replace HHI by four-firm concentration ratio reported by the US Census Bureau, and then divide industries into three groups (high competition, medium competition, and low competition) based on their four-firm concentration ratios. As shown in Table 5, our regression results still hold.

5 Conclusion

In this study, we examine the relationships among contract manufacturing, productivity spillover, and competition. We find that although contract manufacturing in general doesn't have significant impact on labor productivity, it moderates the impact of productivity spillover from suppliers. When competition level is medium, contract manufacturing significantly increases the benefits a focal industry receives from its suppliers' productivity improvements. However, when competition level is high or low, contract manufacturing doesn't help focal industry to take advantage of that.

This research has implications for top managers' vertical scope decisions. It shows that there is a significant interaction among three factors: contract manufacturing,

suppliers productivity spillover, and competition. Contract manufacturing improves labor productivity through its moderating impact on productivity spillovers from suppliers.

For contract manufacturing to improve labor productivity, two conditions must be both satisfied: (1) the industry in which the firm operates has medium competition level; and (2) productivity spillover from suppliers is significant (i.e., suppliers have great productivity improvements). The second condition implies that the dynamic environment faced by suppliers may reduce the effect of contract manufacturing on focal industry, as it increases the uncertainty about suppliers' productivity growth. If at least one of the two conditions is not met, top managers may need to consider other vertical structures such as becoming more vertically integrated, if improving productivity is their goal with high priority.

As stated earlier, in this paper we extend the contract manufacturing/outsourcing literature by examining a more realistic and complex environment, compared with existing papers. However, our model is still a simplification of the reality. For example, in the study we take a static view of suppliers' productivity growth, treating it as exogenous. This assumption holds in the short term. However, in the long run suppliers' productivity growth could be endogenous as it might be influenced by the contract manufacturing decisions made by firms in the focal industry. Similarly, the variable that represents firms' contract manufacturing decisions is also endogenous in a more dynamic environment. Future studies can extend our model by using panel VAR (vector autoregression) models (Abrigo and Love 2016; Sigmund and Ferstl 2021) to study the dynamic relationships among three dependent variables: productivity growth, contract manufacturing or outsourcing, and suppliers' productivity growth.

Another limitation in the study is due to time range of our data (i.e., up to year 2018), we do not consider the impact of COVID-19 pandemic in our model. New studies have shown that the outbreak of the COVID-19 pandemic has disrupted supply chains and negatively affected firms' performances (Atayah et al. 2021; Chowdhury et al. 2021), and as a result the relationships studied in the paper might be influenced by the pandemic. Therefore, a study that examines how COVID-19 affects the impact of outsourcing/contract manufacturing on productivity is desirable.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors did not receive support from any organization for the submitted work. The authors have no relevant financial or non-financial interests to disclose. The authors have no competing interests to declare that are rel-

evant to the content of this article. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

References

- Abrigo MRM, Love I (2016) Estimation of panel vector autoregression in Stata. *Stand Genomic Sci* 16:778–804
- Acemoglu D, Griffith R, Aghion P, Zilibotti F (2010) Vertical integration and technology: theory and evidence. *J Eur Econ Assoc* 8:989–1033
- Aghion P, Griffith R, Howitt P (2006) Vertical integration and competition. *Am Econ Rev* 96:97–102
- Aiken LS, West SG (1991) Multiple regression: Testing and interpreting interactions. Sage Publications Incorporated
- Amiti M, Wei S-J (2009) Service offshoring and productivity: Evidence from the US. *World Econ* 32:203–220
- Arvanitis S, Loukis EN (2013) Outsourcing and firm performance - a comparative study of Swiss and Greek firms. *Ind Corp Chang* 22:771–806
- Atayah OF, Dhiab MM, Najaf K, Frederico GF (2021) Impact of COVID-19 on financial performance of logistics firms: evidence from G-20 countries. *J Glob Oper Strateg Sourc*
- Azadegan A, Dooley KJ (2010) Supplier innovativeness, organizational learning styles and manufacturer performance: An empirical assessment. *J Oper Manag* 28:488–505
- BLS (2017) Industry Productivity Measures. In: BLS handbook of methods
- Broedner P, Kinkel S, Lay G (2009) Productivity effects of outsourcing: New evidence on the strategic importance of vertical integration decisions. *Int J Oper Prod Manag* 29:127–150
- Capolupo R, Amendolagine V, Ferri G (2017) Offshore-sourcing strategies and the puzzle of productivity: a micro-level analysis. *J Glob Oper Strateg Sourc*
- Chan MFS, Chung WWC (2002) A framework to develop an enterprise information portal for contract manufacturing. *Int J Prod Econ* 75:113–126
- Cheng L-C, Cantor DE, Grimm CM, Dresner ME (2014) Supply chain drivers of organizational flexibility - A study of US manufacturing industries. *J Supply Chain Manag* 50:62–75
- Cheng L-C (2011) Assessing performance of utilizing organizational modularity to manage supply chains: Evidence in the US manufacturing sector. *Int J Prod Econ* 131:736–746
- Cheng L-C, Cantor DE, Dresner M, Grimm CM (2012) The impact of contract manufacturing on inventory performance: an examination of US manufacturing industries. *Decis Sci* 43:889–928
- Chowdhury P, Paul SK, Kaiser S, Moktadir MA (2021) COVID-19 pandemic related supply chain studies: A systematic review. *Transp Res E* 148:102271
- Consoli D, Marin G, Marzocchi A, Vona F (2016) Do green jobs differ from non-green jobs in terms of skills and human capital? *Res Policy* 45:1046–1060
- Dorn D, Katz LF, Patterson C, Van Reenen J (2017) Concentrating on the fall of the labor share. *Am Econ Rev* 107:180–185
- Fatima ST (2016) Productivity spillovers from foreign direct investment: evidence from Turkish micro-level data. *J Int Trade Econ Dev* 25:291–324
- Frésard L, Hoberg G, Phillips GM (2020) Innovation activities and integration through vertical acquisitions. *Rev Financ Stud* 33:2937–2976
- Gibbons R (2005) Four formal (izable) theories of the firm? *J Econ Behav Organ* 58:200–245

- Girma S, Görg H (2004) Outsourcing, foreign ownership, and productivity: evidence from UK establishment-level data. *Rev Int Econ* 12:817–832
- Giroud X, Mueller HM (2010) Does corporate governance matter in competitive industries? *J Financ Econ* 95:312–331
- Golan A, Judge G, Perloff JM (1996) Estimating the size distribution of firms using government summary statistics. *J Ind Econ* 69–80
- Görg H, Hanley A, Strobl E (2008) Productivity effects of international outsourcing: evidence from plant-level data. *Can J Econ* 41:670–688
- Grossman SJ, Hart OD (1986) The costs and benefits of ownership: A theory of vertical and lateral integration. *J Polit Econ* 94:691–719
- Han C, Porterfield T, Li X (2012) Impact of industry competition on contract manufacturing: An empirical study of U.S. manufacturers. *Int J Prod Econ* 138:159–169
- Hart O, Moore J (1990) Property rights and the nature of the firm. *J Polit Econ* 98:1119–1158
- Hijzen A, Inui T, Todo Y (2010) Does offshoring pay? Firm-Level Evidence from Japan. *Econ Inq* 48:880–895
- Hirsch BT, Macpherson DA (2003) Union membership and coverage database from the current population survey: Note. *ILR Rev* 56:349–354
- Jaccard J, Turrissi R, Jaccard J (2003) Interaction effects in multiple regression. Sage
- James G, Witten D, Hastie T, Tibshirani R (2013) An introduction to statistical learning. Springer
- Jiang B, Frazier GV, Prater EL (2006) Outsourcing effects on firms' operational performance: An empirical study. *Int J Oper Prod Manag*
- Kar S, Dutta M (2018) Outsourcing and productivity during economic crisis: evidence from Indian manufacturing firms. *Arthaniti* 17:168–82
- Keats BW, Hitt MA (1988) A causal model of linkages among environmental dimensions, macro organizational characteristics, and performance. *Acad Manag J* 570–98
- Kim YH, Schoenherr T (2018) The effects of supply chain integration on the cost efficiency of contract manufacturing. *J Supply Chain Manag* 54:42–64
- Kotabe M, Mol MJ (2009) Outsourcing and financial performance: a negative curvilinear effect. *J Purch Supply Manag* 15:205–213
- Kotabe M, Parente R, Murray JY (2007) Antecedents and outcomes of modular production in the Brazilian automobile industry: a grounded theory approach. *J Int Bus Stud* 38:84–106
- Lahiri S (2016) Does outsourcing really improve firm performance? Empirical evidence and research agenda. *Int J Manag Rev* 18:464–497
- Lechner C, Lorenzoni G, Tundis E (2016) Vertical disintegration of production and the rise of market for brands. *J Bus Ventur Insights* 6:1–6
- Lee GR, Lee S, Malatesta D, Fernandez S (2019) Outsourcing and organizational performance: The employee perspective. *Am Rev Public Adm* 49:973–986
- Levine R, Lin C, Wei L (2017) Insider trading and innovation. *J Law Econ* 60:749–800
- Lybbert TJ, Zolas NJ (2014) Getting patents and economic data to speak to each other: An 'algorithmic links with probabilities' approach for joint analyses of patenting and economic activity. *Res Policy* 43:530–542
- Maziarczyk A (2020) Impact of outsourcing on the productivity of Polish industrial enterprises. *Zeszyty Naukowe Małopolskiej Wyższej Szkoły Ekonomicznej w Tarnowie* 41–52
- Mazzola E, Bruccoli M, Perrone G (2019) The curvilinear effect of manufacturing outsourcing and captive-offshoring on firms' innovation: the role of temporal endurance. *Int J Prod Econ* 211:197–210
- Mubeen R, Han D, Abbas J, Hussain I (2020) The effects of market competition, capital structure, and CEO duality on firm performance: A mediation analysis by incorporating the GMM model technique. *Sustainability* 12:3480
- Paz LS (2014) Inter-industry productivity spillovers: An analysis using the 1989–1998 Brazilian trade liberalisation. *J Dev Stud* 50:1261–1274
- Rakestraw JR (2020) Investor protection and the substitution effect of corporate governance and product market competition on firm value. *J Acc Audit Financ* 0148558X20936792
- Schilling MA, Steensma HK (2001) The use of modular organizational forms: An industry-level analysis. *Acad Manag J* 44:1149–1168
- Sigmund M, Ferstl R (2021) Panel vector autoregression in R with the package panelvar. *Q Rev Econ Finance* 80:693–720
- Smarzynska Javorcik B (2004) Does foreign direct investment increase the productivity of domestic firms? In: Search of Spillovers through Backward Linkages. *Am Econ Rev* 94:605–627
- Stojčić N, Orlić E (2020) Spatial dependence, foreign investment and productivity spillovers in new EU member states. *Reg Stud* 54:1057–1068
- Strange R, Magnani G (2017) The performance consequences of manufacturing outsourcing: Review and recommendations for future research. *Breaking up the Global Value Chain: Opportunities and Consequences* 217–44
- Swink M, Nair A (2007) Capturing the competitive advantages of AMT: Design–manufacturing integration as a complementary asset. *J Oper Manag* 25:736–754
- Tsay AA, Gray JV, Noh IJ, Mahoney JT (2018) A review of production and operations management research on outsourcing in supply chains: Implications for the theory of the firm. *Prod Oper Manag* 27:1177–1220
- Wang X, Feng Xu, Luo XR, Peng L (2022) Effect of sponsorship disclosure on online consumer responses to positive reviews: The moderating role of emotional intensity and tie strength. *Decis Support Syst* 156:113741
- Wolff EN, Nadiri MI (1993) Spillover effects, linkage structure, and research and development. *Struct Chang Econ Dyn* 4:315–331

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.