# Processing Trade, Market Entry and Firm Performance

DISSERTATION

zur Erlangung des akademischen Grades

Doctor of Philosophy (Ph.D.) in Economics

eingereicht an der Wirtschaftswissenschaftlichen Fakultät
Heinrich-Heine-Universität Düsseldorf


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Abgabedatum: 22.09.2021

# Acknowledgment

I spent a fulfilling four years at the Düsseldorf Institute for Competition Economics (DICE) at Heinrich-Heine-Universität as a doctoral researcher and completed this dissertation. I would like to express my gratitude to many people who have supported me over the last four years.

Firstly, I would like to thank Alexander Rasch. He taught me the paradigm of theoretical modeling and gave me full guidance. His enthusiasm for pushing the boundaries of knowledge continues to affect me. He supported and encouraged me to develop new research ideas and he shared his network with me, for which I am very grateful.

I would also like to thank Joel Stiebale. His detailed and patient counsel improved my understanding of econometrics and deepened my interest in empirical research. I am also very grateful to him for giving me many constructive suggestions on my empirical design. His critical reasoning had a strong impact on me and has made me examine my researches more rigorously.

I am also grateful to Andrea Ciani. Collaborating with him was an enjoyable process that aroused my interest in international trade. He selflessly taught me his expertise, for which I am eternally grateful. Thanks to our discussions, I gradually learned how to explore the essence behind economic phenomena. His encouragement and challenges allowed me to constantly progress.

I also want to thank Changying Li. He was my supervisor during my master's program and has started research projects with me since then. There are many things he has taught me regarding not only research but also life, which have deeply changed the way I think and live.

I would also like to thank Matthias Hunold for introducing me to DICE and for guiding my research.

I also thank the fabulous DICE team. The research discussions, seminars, short-term schools, Christmas parties, and lunch that I had at DICE were all wonderful experiences. Many thanks go to my colleagues, especially Fang, Astrid, Cecilia, Judith, Melinda, and Jannika, for their support.

The Chinese Government Scholarship is gratefully appreciated.

Finally, I want to thank my parents. Their unconditional support enabled me to concentrate on my studies.

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# Introduction

As the basic economic components, firms' development is closely related to the growth of the aggregate economy. Investigation into the determinants of firm performance is a constant theme for both theoretical and empirical research. With the in-depth development of global economic integration, more and more economies are participating in Global Value Chains (GVCs) through different trade regimes. Exposure to trade is therefore believed to be a prominent driving force of firm development (Krugman, 1981; Melitz, 2003; De Loecker, 2013; Jarreau and Poncet, 2012; Garcia-Marin and Voigtländer, 2019). Different from developed economies, processing trade is often a leading channel for the internationalization of firms in emerging economies. An example in point is China. China has achieved a drastic growth in trade flows since its reform and opening up in 1978 by motivating processing trade, with the export scale increasing tenfold from 2000 to 2019 with processing trade accounting for more than half of total exports before 2011.

Processing production refers to the assembly or processing of the intermediate inputs that are largely imported into the products in line with foreign specifications, and the following re-export of processed finished products. Multiple preferential policies are granted to processing trade in China, attracting considerable foreign direct investment (FDI) inflows, which leads to foreign-invested firms gaining the primary position among firms that are involved in processing trade. The knowledge embodied in processing trade and the imported capital goods brought by the FDI are both compelling. Trade openness and international knowledge diffusion have thus been widely seen as the driving forces for the Chinese economic miracle in the past decades.

However, the possible gaps in the performance of different firms pursuing processing trade and the sources of gaps, if any, both remain unclear. In the first chapter, we investigate the differences in performance among Chinese exporting firms differently involved in processing trade. We distinguish firms pursuing only processing trade from firms that are also involved in ordinary trade (hybrid exporters). We rely on detailed balance sheet data and on customs data on firm transactions for the period 2000–2007. Results show that hybrid exporters outperform firms exclusively involved in processing trade in terms of value added, productivity, profits, and revenue in the different export destinations. We find that this difference in performance is associated with the increase in Chinese domestic value added. Hybrid exporters can rely to a larger extent than pure processing exporters on domestic inputs which, during this period, benefited from remarkable increases in productivity. Hybrid exporters also conduct more R&D activities and are thereby able to sell processing products of better quality yet at competitive prices, which contributes to their larger market shares in foreign markets with respect to pure processing firms.

A justified argument is that when foreign firms that outsource processing tasks perceive emerging Chinese firms more like competitors than partners, they tend to block the knowledge diffusion from processing trade. In the second chapter, we first demonstrate the incentive of foreign firms to prevent spillovers by an outsourcing model. We then focus on spillovers from processing trade on the firm's outcomes measured by productivity and non-processing (ordinary) export performance, including product varieties, product quality, the number of overseas markets, and export revenue. We distinguish spillovers on firms engaged in processing trade (intra-firm spillovers) from spillovers from processing firms on domestic non-processing firms (inter-firm spillovers). The latter is further classified as horizontal spillovers within the industry and backward spillovers through vertical linkages.

We find the upper limit of intra-firm spillovers on productivity and product varieties. We also find negative backward productivity spillovers on domestic non-exporting firms and positive horizontal productivity spillovers on domestic ordinary exporters in the base year (2002), which both decrease in scale in the following years.

Investigation on the possible mechanisms suggests different drivers for the shrinking patterns of distinct inter-firm spillovers. Processing exporters spread production and product information to other non-processing firms and generate diverse input demands, steering domestic upstream non-exporting firms toward product development rather than productivity improvement. This disruption to productivity is mitigated by the gradual technological advances of domestic non-exporting firms. No evidence is found for the new product exploration or R&D activities of domestic ordinary exporters reducing their productivity gains from horizontal spillovers, implying that the decreasing trend of this sort of spillovers results from external causes such as controls over spillovers. Thus, we suggest the unsustainable learning opportunity of the processing trade in the long run.

The above chapters explain the role of participation in processing trade for firm performance. Relative to performance, another critical challenge for firms is market entry. After all, there is no point in discussing firm performance until there has been a successful entry. Firms may nevertheless encounter substantial entry barriers imposed by competitors in international markets, among which the foreclosure on inputs ranks as one of the top. Plenty of empirical evidence points out the prevalence of vertical foreclosure (Waterman and Weiss, 1996; Hastings and Gilbert, 2005; Hortaçsu and Syverson, 2007; Crawford et al., 2018). For instance, Boehm and Sonntag (2020) propose that the international buyer-seller relationships between large US and foreign firms in a wide range of industries are more prone to break when the suppliers integrate with one of the buyer's competitors than integrating with non-competitors, implying that the distorting effects of vertical foreclosure on the market competition have already spread in the global production network.

Research and development (R&D) alliances arising from the innovation-related challenges and risks facing firms have nowadays become an increasingly common form of strategic cooperation (Sampson, 2007). The transfer and exchange of knowledge within alliances essentially serve as intangible asset bonuses for partners. Therefore, R&D alliances are supposed to play a role in areas where technology compensations can make up for insufficient financial incentives. In the third chapter, we thereby examine the capability of an R&D alliance in mitigating vertical foreclosure when firms encounter survival risks in the wave of a product update, and complete extraction of the entrant's profit is infeasible.

We consider the model where a vertically integrated upstream monopolist also supplying an independent downstream firm faces a financially constrained yet innovative downstream entrant. The entrant has the potential for upstream entry on the premise of completion of the update. Vertical foreclosure could be applied due to the incomplete rent extraction resulting from the entrant's financial constraints and opportunistic upstream entry. Technology licensing by the entrant to the vertically integrated incumbent under an R&D alliance can enhance the incumbent's survival probability in the downstream market and upstream profit, and also intensify downstream competition. The R&D alliance therefore facilitates market entry in the case of a modest efficiency advantage of the upstream monopolist and a high joint survival probability of partners.

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# 1
# Born similar, develop apart: Evidence on Chinese hybrid exporters

*Joint work with Andrea Ciani*

## 1.1 Introduction

Export processing is a trade regime in which producers of final products offshore the last stages of production to manufacturers based in emerging economies. Under this regime, the various components of a final product are manufactured in different parts of the globe from where they are shipped to the country home of the processing firm for final assembly. Assembled products are then exported back, mostly to developed economies. Processing trade has been adopted by developing countries to benefit from their low labor cost and integrate into the final steps of Global Value Chains (GVCs). Export processing and offshoring have sizable effects on the host economies for what concerns employment volatility (Bergin et al., 2009, 2011) and returns to skills (Sheng and Yang, 2017). Processing trade accounted for the majority of Chinese exports in the first decade of the 2000s and for 25 percent of China's total trade in 2019 thus representing a relevant share of the country's trade surplus.[1]

The literature has shown that the low productivity of processing exporters affects trends in aggregate productivity in China (Dai et al., 2016). Nevertheless, Chinese exporters can pursue processing trade to a different extent, as firms can decide whether to devote some production lines to processing trade and others to ordinary trade, within the same plant. Our aim is to investigate the relation between firm performance and the relevance of processing trade for firm's exports. Given this, we first distinguish those exporters that are only involved in processing trade from those which are also doing ordinary trade (hybrid exporters). We then assess differences in performance between these firms and investigate the economic channels determining them, focusing both on external and internal factors to the firm.

Our empirical investigation relies on two sources of data. The *Annual Survey of Industrial Firms* (ASIF) available from the National Bureau of Statistics of China for the period 2000-2007 and the *Chinese Customs Trade Statistics* (CCTS), for the period 2000-2007, available from the General Administration of Customs of China. ASIF provides balance sheet data on a panel covering all state-owned firms and non-state-owned firms with annual sales of more than 5 million RMB. CCTS provides detailed information on import and export transactions at the product level for Chinese exporters.

We first focus on differences in performance between purely processing and

[1] Data obtained from the General Administration of Customs (GACC), People's Republic of China.

hybrid exporters.[2] Taking into account relevant firm-level determinants and unobserved factors varying at the industry-province level over time, we find that hybrid exporters report 13.7 percent higher value added, 21.6 percent higher profit, 10 percent higher revenue, 17.5 percent higher labor productivity and, on average, 10.6 percent higher total factor productivity (TFP), compared to purely processing firms. Our estimates also show that hybrid firms report higher revenues from their processing exports than purely processing firms when shipping the same products to the same destination markets.

Firms' participation in distinct trade regimes can be endogenously determined by their inherent differences in traits, as less productive and more financially constrained firms might self-select into only-processing trade flows while productive firms might be more engaged in ordinary trade (Dai et al., 2016; Manova and Yu, 2016). We observe that processing trade accounts for a large share of exports from hybrid firms in our sample. In our empirical investigation, we control for firm-level characteristics which might affect the choice of the trade regime.

We focus on firm-level domestic value added in exports which measures the total, domestically created, value contained in exports as the factor explaining differences in performance. We find that hybrid firms report a higher domestic value-added ratio (DVAR) of processing exports as they are able to benefit from the increased productivity of domestic input suppliers (Kee and Tang, 2016).[3] The DVAR of processing exports of hybrid exporters is positively associated with firm-level performance. An increase in DVAR by one unit increases value added by 9.0 percent, profit by 17.6 percent, and labor productivity by 10.3 percent. Our findings confirm that hybrid exporters substitute imported inputs with domestic inputs and achieve a higher DVAR. We show that firms benefiting from a higher DVAR operate in industries which receive more FDI inflows and benefit from larger reductions in input tariffs which stimulate competition and efficiency upgrading among Chinese input suppliers.

These factors lead hybrid firms to export products of higher quality, as measured by unit value and the quality proxy proposed by Khandelwal et al. (2013). Hybrid exporters also tend to import more equipment from abroad, spend more in R&D, and are more specialized as they supply a lower number of processed HS products to different destination markets than purely processing firms.

[2] We are not studying the behavior of regime switchers as our aim is to compare the performance of firms which are either pure processing or hybrids each of the years under investigation.

[3] As vertical integration might play a role in firms' decisions of input sources, we investigate differences in vertical integration between hybrid and pure processing exporters, and no significant difference is found. More details are reported in section 1.5.

This paper is related to several strands of the literature. First, it is connected to studies analyzing the behaviour of exporting firms and learning by exporting. Van Biesebroeck (2005) and De Loecker (2007), find that exporting firms are more productive than non-exporting firms. Lu et al. (2010) show that this finding is mostly due to foreign-owned firms. Manova and Zhang (2012) find that Chinese exporters charging higher prices earn higher revenues in each destination, report larger worldwide sales, and enter more markets. De Loecker (2013) finds significant productivity gains from entering export markets, while Garcia-Marin and Voigtländer (2019) observe sizable efficiency gains after export entry which are then passed-on to customers via lower prices. The present study contributes to this strand of the literature by providing evidence on the different performance of Chinese exporters, depending on the trade regime under which they operate. Once taking into account several firm-level confounders, the trade regime chosen by exporters is associated with remarkable differences in outcomes.

A flourishing stream of the literature focuses on the implications of processing trade both at the aggregate and at the microeconomic level. Koopman et al. (2012) find that the domestic content of exports can be overestimated for those countries actively engaging in processing trade when employing traditional methods to calculate value added. Kee and Tang (2016) analyze the determinants of domestic value added focusing on Chinese processing exporters. They show that the substitution of domestic for imported materials by individual processing exporters led to an increase of China's domestic content in exports during the period 2000-2007.

Dai et al. (2016) find that pure processing exporters are less productive than non-processing exporters, and also report lower profitability, pay lower wages, and have lower capital intensity. They conclude that not distinguish between processing and non-processing exporters leads to the misleading finding that Chinese exporters in the early 2000s were less productive than non-exporting firms, as recently observed by Malikov et al. (2020). Manova and Yu (2016) investigate the choice between export processing and ordinary exports and argue that financial constraints are more binding for ordinary exports, thus leading firms with lower access to finance to specialize in export processing. Our analysis identifies the increase in domestic value added as a channel explaining the better performance of hybrid exporters with respect to purely processing exporters on top of credit availability, and highlights that gaps in performance are also associated with differences in the quality of exported products.

This study is also related to the vast literature on the effects of China's export boom given the centrality of GVCs (Grossman and Rossi-Hansberg, 2008; Costinot et al., 2013). Luck (2019) finds that Chinese exporters control a larger share of value added as firms move down the supply chain, towards final production. Johnson and Noguera (2012) show that the US-China trade imbalance in 2004 is 30 to 40 percent smaller when trade is measured in value added. Our findings suggest that Chinese exporters with access to domestic inputs report a better performance while still being placed in the final steps of the value chain.

This paper unfolds as follows. Section 1.2 outlines China's export processing regime. Section 1.3 describes the data at our disposal. Section 1.4 reports empirical evidence on the performance of firms operating under different trade regimes. Section 1.5 investigates the determinants of the performance of hybrid exporters. Section 1.6 reports robustness checks. The last section concludes.

## 1.2 Processing trade in China

China's processing trade refers to the trade regime where firms import part or all of the raw materials or intermediate inputs from abroad and re-export the finished products to foreign markets after assembly or processing. Processing trade stems from the early stage of China's reform and opening-up initiatives and was introduced with the aim of solving the contradiction between China's serious lack of capital and technology and the urgent need to open the country and integrate China with the global economy. The No. 80 document issued by the State Council of China in 1987 presented clear instructions for China to seize the favorable opportunity to further develop trade regimes such as processing and assembly with supplied inputs.[4] The document stated:

"[...] practice shows that the development of the trade regime of processing and assembly with supplied materials will help increase employment and the inflow of foreign currency, make up for insufficient funds, introduce advanced and applicable technologies, equipment, and scientific management methods. It enables firms to understand how international markets work and improve the quality of export products, and increases the country's fiscal revenue. [...] This trade regime is worth promoting."

China has implemented a number of special preferential policies to develop processing trade. First, according to the *Regulations Governing Customs Control on the Importation and Exportation of Goods for Inward Processing* (1988), im-

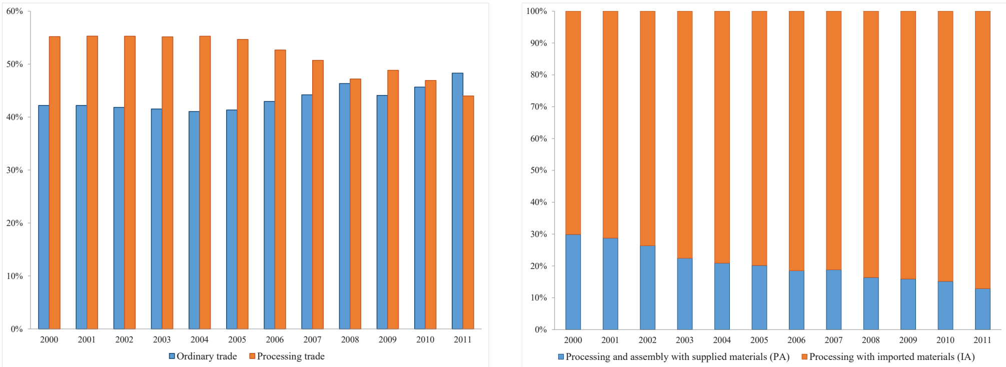
[4] Note forwarded by the General Office of the State Council given the Ministry of Economy and Trade's request for instructions on seizing favorable opportunities to further develop processing and assembly with supplied materials, 1987.

ported inputs used for processing production are exempt from import tariffs and product taxes (or value-added tax), as long as all finished products are re-exported to foreign markets. Exports of processed finished products are also exempt from export tariffs. If only part of the finished product is exported, only the imported inputs used for export production are exempt from tariffs. Second, foreign-invested firms are granted the treatment of corporate income tax exemption for 2 years and halved taxation for 3 years from the tax year in which the first business income is computed. Moreover, during the period investigated in our study (2000-2007), two additional preferential policies were implemented. For foreign-invested firms located in special economic zones or engaged in production and located in economic and technological development zones, and for foreign firms setting up production in special economic zones, corporate income tax was levied at a reduced rate of 15 percent. Exporting firms also benefited from a specific income tax reduction conditional on annual exports accounting for more than 70 percent of the firm's total output. Since most firms involved in processing trade fulfill this last requirement, they were eligible for the tax incentive.

The superposition of multiple preferential policies greatly reduced investment costs associated with production for processing trade. Therefore, processing trade promoted the development of China's trade surplus by absorbing FDI and led China's integration into global value chains. As shown in Figure 1.1(a), before 2005, processing exports account for 55 percent of China's total exports. Hence processing trade is believed to be a center for the Chinese trade boom of the early 2000s. The proportion of processing exports declines after 2006 due to industrial development and ordinary exports accounting for the majority of Chinese exports after 2010.

Processing trade consists of two main subordinate trade regimes, processing and assembly with supplied materials (PA), and processing with imported materials (IA). The difference between these two is the ownership of the production materials. In the PA regime, foreign firms own production materials and supply firms engaged in processing production with inputs, while the latter only receive processing fees from assembling or processing inputs. In the IA regime, Chinese firms purchase inputs from abroad for processing production and then sell the finished products to the foreign firms. The PA regime generates little demand for domestic production materials as firms mostly do assembly and processing, whereas under the IA regime, firms have greater autonomy in production and might demand more domestic inputs. The greater the demand for domestic inputs, the stronger the promotion to the development of Chinese domestic suppliers. Figure 1.1(b)

Figure 1.1: China's export composition in 2000-2011, by trade regime




(a) Gross export composition (b) Processing export composition

*Source: China Customs Statistical Yearbook* and CCTS.

shows that in the period 2000 to 2011, the proportion of IA in China's processing exports expands from 70 percent in 2000 to 87 percent in 2011, implying that IA processing trade yields more domestic procurement and extends the domestic production chain. In section 1.6 we will discuss the effects of engaging in PA or IA on firm performance.

## 1.3 Data

Our empirical investigation relies on two sources of data. The *Annual Survey of Industrial Firms* (ASIF) available from the National Bureau of Statistics of China for the period 2000-2007, a panel covering all state-owned and non-state-owned firms with annual sales of more than 5 million RMB.[5] ASIF provides production statistics on Chinese industrial firms from mining and logging to manufacturing and public utilities, and provides financial information on the balance sheet, income statement, and cash flow statement of firms, as well as firm-specific information, such as firm name, the year and month of establishment, address, industrial classification, employment, and ownership structure. For instance, ASIF data for year 2004 covers 90 percent of total sales of all industrial firms in China, compared to the Chinese Economic Census for the same year. Since China's processing trade mainly comes from the manufacturing industry, we only rely on the records of manufacturing firms whose two-digit China's GB/T industry classification codes

[5] This is equivalent to 0.6 million US dollars based on the bilateral exchange rate in 2004.

are between 13 and 42.[6] Following Dai et al. (2016), we drop: (1) records where the main variables are negative or missing, including industrial sales, export value, revenue, employment, total fixed assets, net fixed assets, and intermediate inputs; (2) records where the number of employees is less than 8; (3) records where the export value exceeds the total industrial sales, or the total assets are less than the total fixed assets or current assets, or the accumulated depreciation is less than the current year's depreciation; (4) records where the month of establishment is greater than 12 or less than 1, or the year of establishment is greater than the year of record; (4) trade intermediaries.[7]

The second database available to us is the *Chinese Customs Trade Statistics* (CCTS), for the period 2000-2007, available from the General Administration of Customs of China. CCTS provides detailed information on import and export transactions at the HS 8-digit level for Chinese trade flows, including the transaction value in US dollars, quantity, unit price, trade regime, exporting destinations or importing sources of each transaction, and firm-specific information such as firm name, zip code, and phone number. Since the Harmonized System was adjusted in 2002 and 2007, we convert all transaction records in our sample to the 2002 version of Harmonized System.

As the two datasets do not have a common identifier that allows us to match firm-level transaction data and production data, we first use the firm name as the identifier for matching. For records that fail to be matched by firm name, we use the last 7 digits of the phone number and the zip code as the second identifier. We eliminate the characters in the identifiers that would interfere with the matching so as to improve accuracy, and successfully merge 53 percent of exporters in ASIF.[8] The merged database includes 273,828 observations from 88,212 exporters, on average accounts for about 40 percent of China's total exports and 52 percent of processing exports from 2000 to 2007, giving then a good representation of

[6] China's GB/T industry classification system is referred to as Chinese industry classification (CIC). The mapping between industry codes and names is provided in the Appendix.

[7] We draw on the method of Ahn et al. (2011) to identify trade intermediaries. The names of these firms have Chinese characters with the meaning of "exporter", "importer" or "trading" in English.

[8] For example, firms may use parentheses in their names to indicate the locating city or industrial area, such as Sanyo Electric (Shekou) Co., Ltd. However, in ASIF and CCTS, one party may use full-angle parentheses while the other party may use half-angle parentheses, which leads to an unsuccessful match for the same firm. Hence the following characters are eliminated from the identifiers: full-width and half-width brackets, single and double quotes; hyphens, underline, dot, square brackets, slash, asterisk, and inequality signs. In this way we are able to merge more exporters compared to the literature. For instance, Dai et al. (2016) merge about 45 percent of exporters in ASIF for the period 2000 to 2006.

aggregate Chinese exports.[9]

### 1.3.1 Measuring firm performance

The first goal of the present study is to assess differences in performance among firms differently involved in processing trade. Therefore, we classify exporters into three categories according to the trade regimes to which they refer each recorded year: (1) processing exporters ($Proc$), firms that only report processing exports each year; (2) non-processing exporters ($NProc$), firms that only report ordinary exports each year; (3) hybrid exporters ($Hybrid$), firms that report both ordinary and processing exports each year. The sample employed in the main body of this study excludes exporters that alter their trade regimes during the sample period, as we focus on the performance of exporters consistently participating in a given trade regime. Since our aim is to assess factors explaining possible differences in performance among firms pursuing processing trade, non-processing exporters are mostly considered for the robustness checks reported at the end of our empirical investigation.

Following the literature (Amiti and Konings, 2007; Halpern et al., 2015; Baggs and Brander, 2006), we consider firm productivity and profitability as indicators of firm performance. We employ revenue total factor productivity (TFP) and labor productivity ($lnLabPro$) as measures of the firm productivity. The literature on TFP (Brandt et al., 2012; Yu, 2015) uses the industry-level price index to deflate firms' sales, yet by doing so the heterogeneity of firms is ignored thus leading to a biased estimate (Klette and Griliches, 1996; Eslava et al., 2004; Foster et al., 2008; De Loecker, 2011). The magnitude of this bias increases when measuring productivity of multi-product firms. Most importantly, we investigate firm heterogeneity within industries so pricing heterogeneity is more important than one studying an industry-level treatment such as tariffs. In order to accurately capture the price trends of firms, we adopt the method proposed by Smeets and Warzynski (2013) to construct firm-level price index by means of the firm-product level trade information disclosed in CCTS and then deflate exporters' output. We employ the semi-parametric estimation methods developed by Olley and Pakes (1996) and Ackerberg et al. (2015) and measure total factor productivity as $TFP(OP)$ and

[9] Our merged data for exporters is comparable to Dai et al. (2016). Their data merged between ASIF and CCTS spans from 2000 to 2006, includes 225,853 observations from 68,865 firms. Table A1 in the Appendix demonstrates that the compositions of exporters by trade regime in the sample of Dai et al. (2016) and ours are very similar.

$TFP(ACF)$.[10] We compute three variables using the statistical data provided by ASIF to measure the profitability of firms: value added ($VA$), profit ($Profit$), and revenue ($Revenue$). Following the procedure applied on productivity indicators, variables measuring profitability are also deflated using the firm-level price index.

### 1.3.2 Control variables

We control for firms' characteristics measuring inherent traits and financial constraints. We use the number of years a firm has been in operation ($Age$) to measure firm age, and use the number of employees ($Labor$) and total assets ($Asset$) of the firm to proxy firm size. In order to capture the ownership structure of firms, $Foreign\ share$ is the ratio between foreign capital and total capital. According to Manova and Yu (2016), financing constraints affect the choice of exporters on trade regimes, and firms facing tighter financial constraints tend to do processing trade. To reflect financial constraints faced by firms, we construct the variables $Liquidity$, which measures the difference between current assets and liabilities divided by total assets, and $Interest\ rate$, which is the ratio between expenses on interest and total assets. In addition, we take into consideration public subsidies received by each firm ($Subsidy$).

Table 1.1 provides a statistical description of the aforesaid variables for the different groups of exporters observed in our sample. Exporters engaged in different trade regimes seem to report differences in performance. On average, hybrid exporters report better results than processing exporters, and have better profitability, yet comparable productivity relative to non-processing (ordinary) exporters.[11] The three groups of exporters have different characteristics as well: as expected, processing exporters have the highest foreign share on average. Processing and non-processing exporters look similar to hybrid exporters looking at firm age. Hybrid exporters tend to be larger and receive more subsidies than processing exporters and non-processing exporters. At a first glance, the different groups do not report sizable differences in financial constraints.

[10] The Appendix provides details on the procedure followed to compute the two variables.
[11] TFP measures are demeaned by the average of 4-digit industry-year combinations.

Table 1.1: Descriptive statistics

| | Count | Mean | Median | SD |
|---|---|---|---|---|
| *Profitability and Productivity* | | | | |
| *Panel A: Processing Exporters* | | | | |
| Value added | 22,441 | 25,686.51 | 6,359 | 120,187.94 |
| Profit | 22,441 | 3,178.60 | 205.00 | 32,583.21 |
| Revenue | 22,441 | 119,641.90 | 27,417 | 658,243.48 |
| TFP(OP) | 21,739 | -0.22 | -0.24 | 1.05 |
| TFP(ACF) | 21,738 | -0.16 | -0.24 | 0.60 |
| ln Labpro | 21,741 | 3.14 | 3.03 | 1.21 |
| *Panel B: Hybrid Exporters* | | | | |
| Value added | 37,312 | 41,903.14 | 9,809 | 251,353.23 |
| Profit | 37,312 | 8,031.40 | 803.00 | 53,956.42 |
| Revenue | 37,312 | 165,818.85 | 39,171.50 | 767,201.56 |
| TFP(OP) | 36,403 | 0.12 | 0.13 | 1.03 |
| TFP(ACF) | 36,376 | 0.04 | -0.03 | 0.62 |
| ln Labpro | 36,413 | 3.69 | 3.63 | 1.22 |
| *Panel C: Non-processing Exporters* | | | | |
| Value added | 56,239 | 19,234.21 | 5,525 | 156,057.52 |
| Profit | 56,239 | 4,175.68 | 479.00 | 60,744.32 |
| Revenue | 56,239 | 67,623.57 | 22,270 | 400,678.11 |
| TFP(OP) | 55,060 | 0.01 | 0.00 | 1.03 |
| TFP(ACF) | 55,037 | 0.04 | -0.02 | 0.62 |
| ln Labpro | 55,066 | 3.72 | 3.65 | 1.21 |
| *Firm Characteristics* | | | | |
| *Panel A: Processing Exporters* | | | | |
| Foreign share | 22,381 | 0.89 | 1.00 | 0.27 |
| Age | 22,441 | 8.39 | 8.00 | 4.54 |
| Employment | 22,441 | 492.11 | 250.00 | 839.65 |
| Total assets | 22,441 | 82,866.38 | 25,619 | 339,051.30 |
| Subsidy | 22,441 | 46.09 | 0.00 | 1,308.53 |
| Liquidity | 22,441 | 0.14 | 0.13 | 0.34 |
| Interest rate | 22,441 | 0.00 | 0.00 | 0.05 |
| *Panel B: Hybrid Exporters* | | | | |
| Foreign share | 37,258 | 0.75 | 1.00 | 0.37 |
| Age | 37,312 | 9.01 | 8.00 | 7.79 |
| Employment | 37,312 | 487.10 | 229 | 1,129.86 |
| Total assets | 37,312 | 141,377.31 | 32,612.50 | 561,684.01 |
| Subsidy | 37,312 | 218.53 | 0.00 | 5,700.50 |
| Liquidity | 37,312 | 0.10 | 0.11 | 0.32 |
| Interest rate | 37,312 | 0.01 | 0.00 | 0.02 |
| *Panel C: Non-processing Exporters* | | | | |
| Foreign share | 56,135 | 0.38 | 0.25 | 0.43 |
| Age | 56,239 | 8.51 | 6.00 | 9.49 |
| Employment | 56,239 | 242.36 | 119.00 | 541.47 |
| Total assets | 56,239 | 67,642.98 | 15,967 | 405,158.11 |
| Subsidy | 56,239 | 138.24 | 0.00 | 1,831.29 |
| Liquidity | 56,239 | 0.10 | 0.09 | 0.33 |
| Interest rate | 56,239 | 0.01 | 0.00 | 0.02 |

### 1.3.3 Additional differences among exporters engaged in processing trade

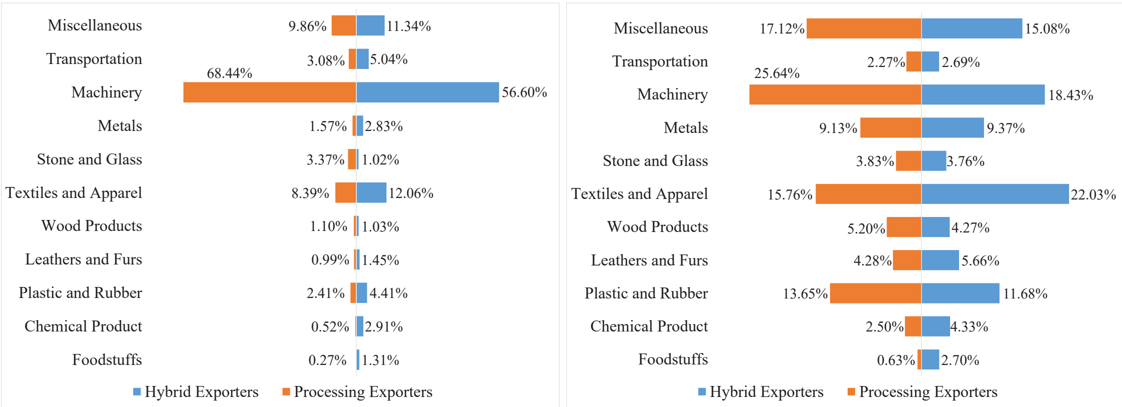
We now describe additional characteristics of the firms in the sample that might play a role in our investigation. First, we focus on the sectoral distribution of processing exporters. One can classify exported products into 11 industries according to the HS 2-digit code.[12] We calculate the distributions of hybrid exporters and processing exporters as well as the proportion of their processing export revenue in each industry, results are reported in Figure 1.2. The distribution of export revenue conveys the following messages. Processing exports of hybrid exporters and processing exporters mainly come from two industries: textiles and apparel and machinery. Together these industries account for about 69 percent and 77 percent of the processing exports for hybrid exporters and purely processing exporters, respectively. However, hybrid exporters and processing exporters report different levels of participation in the two industries. Machinery accounts for a larger share in the exports of processing exporters than in the total processing exports of hybrid exporters, which are respectively 68.4 percent and 56.6 percent; while textiles and apparel constitute a larger share in the processing exports of hybrid exporters than in the exports of purely processing exporters, 12.1 percent and 8.4 percent, respectively.

The distribution of exporters across industries describes a similar pattern, as hybrid exporters tend to focus more on textiles and apparel than on machinery production, and purely processing exporters do the opposite. Machinery production attracts the majority of processing exporters, at the second place with the most processing exporters is textiles and apparel. Combining this with Figure 1.2(a) implies that the export revenue of hybrid exporters is concentrated in few large firms, as 56.6 percent of export revenue comes from only 18.4 percent of hybrid exporters. On the contrary, the largest share of export revenue comes from a large number of processing exporters, indicating that processing exporters engaged in machinery production on average are of a smaller scale than hybrid exporters in the same industry. A prominent fact is that light industries such as textiles and apparel are labor-intensive and have low value added, while machinery is a capital-intensive industry generating high value added. The differences in the sectoral distribution of hybrid exporters and processing exporters may be a potential source of hetero-

[12] These 11 sectors are: (1) food products (HS2 codes between 15 and 23); (2) chemical products (28-38); (3) plastic and rubber (39-40); (4) leather and fur (41-43); (5) wood products (44-49); (6) textiles and apparel (50-67); (7) stone and glass (68-71); (8) metals (72-76; 78-83); (9) machinery (84-85); (10) transportation (86-89); (11) miscellaneous (90-96).

geneity and we will take them into account in the empirical analysis.

Figure 1.2: Sectoral distribution of exporters engaged in processing trade



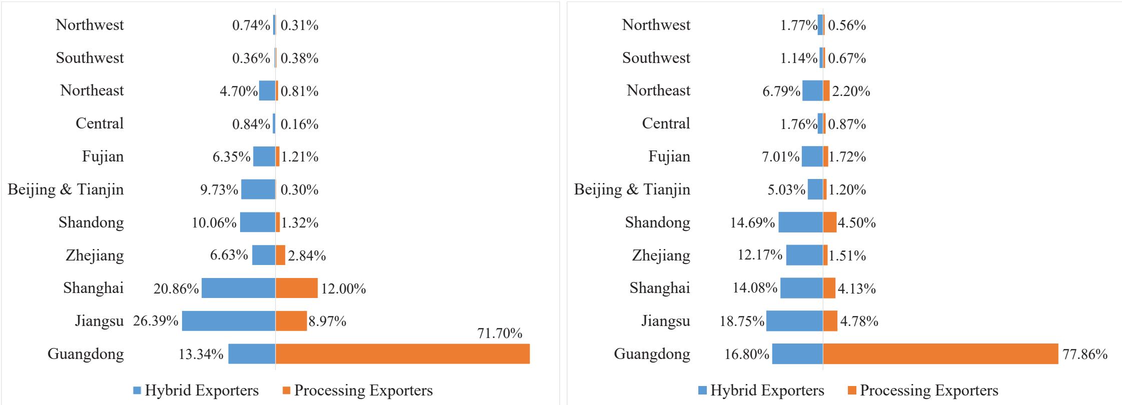

(a) Sources of processing export revenue

(b) Distribution of firms

We also take into account the location of hybrid exporters and processing exporters in China, as a report issued by the Hong Kong Constitutional and Mainland Affairs Bureau (Lam Tin-fuk et al., 2007) discusses the severe cost increases faced by firms in southern mainland China. The report indicates that the Pearl River Delta region of the Guangdong Province, which benefits from the geographical proximity to Hong Kong, attracts direct investments from foreign countries as well as from districts like Hong Kong. The remarkable accumulation of firms in the Pearl River Delta region has led to rising local production costs, which are mainly manifested by: tight labor supply and rising labor costs; limited land use and rising land costs; unstable supply of electricity and water, and increasing electricity prices and sewage treatment costs due to strengthened environmental protection requirements. Therefore, many firms receiving investments from Hong Kong have sprouted plans to move part or all of their production activities to other Chinese provinces so as to avoid the expensive production costs in the region.

Given this information, we consider the role of firms' location in determining performance. We draw on the classification of Brandt et al. (2020) for Chinese provinces. Figure 1.3 illustrates the location of hybrid exporters and processing exporters. It is apparent that hybrid exporters and processing exporters report completely different patterns of geographical distribution: more than 70 percent of the export revenue of processing exporters comes from firms based in the Guangdong Province; whereas hybrid exporters are more evenly distributed in various provinces. It is worth mentioning that the Guangdong Province only ranks third among the sources of processing exports of hybrid firms with 13.3 percent.

Figure 1.3: Geographical distribution of exporters engaged in processing trade




(a) Sources of processing export revenue

(b) Distribution of firms

## 1.4 Firm performance under different trade regimes

In order to investigate differences in performance between hybrid exporters and processing exporters, we estimate the following empirical specification:

$$Y_{ijrt} = \alpha + \beta Hybrid_{ijr} + X'_{ijrt}\gamma + \eta_{jrt} + \epsilon_{ijrt}, \tag{1.1}$$

where $Y_{ijrt}$ is the dependent variable measuring the profitability and productivity of firm $i$ belonging to industry $j$ and region $r$ in year $t$: the logarithm of value added, profits, revenue, and labor productivity, as well as measures of total factor productivity, $TFP(OP)$ and $TFP(ACF)$. $Hybrid_{ijr}$ is a dummy variable that equals to 1 for hybrid exporters, that is, firms reporting both processing exports and ordinary exports each recorded year; the comparison group is processing exporters, that is, firms reporting only processing exports each recorded year. Therefore, the coefficient $\beta$ represents the difference between hybrid exporters and processing exporters for a specific performance indicator. $X_{ijrt}$ is a vector of firm-level control variables accounting for the firm's size (measured by the logarithm of employment and total assets), the logarithm of firm's age, ownership structure (measured by the share of foreign capital in total capital), financial constraints (measured by liquidity and interest rate), and the logarithm of public subsidies received by the firm, as discussed in section 1.3.2. $\eta_{jrt}$ is the 4-digit industry-year-province fixed effect, introduced to consider the time-varying unobserved characteristics of each industry in each province.[13]

Table 1.2 reports the results for specification (1.1). In columns (1)-(3), we consider the profitability of firms, and respectively regress the logarithm of value added, profit, and revenue on the dummy variable indicating the status of a firm's participation in processing export and ordinary export. In columns (4)-(6), we focus on firm's productivity, and respectively regress $TFP(OP)$, $TFP(ACF)$, and the logarithm of labor productivity on our explanatory variable. In all specifications, we control for firm size, age, ownership structure, and financial constraints.

Table 1.2: Firm-level performance comparison

| | (1)<br>ln VA | (2)<br>ln Profit | (3)<br>ln Revenue | (4)<br>TFP(OP) | (5)<br>TFP(ACF) | (6)<br>ln LabPro |
|---|---|---|---|---|---|---|
| Hybrid | 0.137*** | 0.216*** | 0.100*** | 0.138*** | 0.074*** | 0.175*** |
| | (0.019) | (0.039) | (0.022) | (0.019) | (0.025) | (0.026) |
| Foreign share | -0.011 | 0.152*** | -0.009 | -0.079*** | -0.042* | -0.026 |
| | (0.023) | (0.046) | (0.018) | (0.021) | (0.023) | (0.025) |
| ln Age | 0.038*** | -0.201*** | 0.036*** | -0.004 | -0.044*** | -0.047*** |
| | (0.010) | (0.027) | (0.011) | (0.012) | (0.015) | (0.017) |
| ln Asset | 0.611*** | 0.849*** | 0.653*** | 0.327*** | 0.348*** | 0.244*** |
| | (0.021) | (0.025) | (0.021) | (0.016) | (0.020) | (0.014) |
| ln Labor | 0.360*** | 0.216*** | 0.302*** | -0.103*** | -0.414*** | |
| | (0.015) | (0.022) | (0.013) | (0.014) | (0.044) | |
| ln Subsidy | 0.004 | 0.033*** | 0.007* | 0.010** | 0.009*** | -0.010** |
| | (0.004) | (0.007) | (0.004) | (0.004) | (0.003) | (0.004) |
| Liquidity | 0.247*** | 0.984*** | 0.168*** | 0.391*** | 0.108*** | 0.373*** |
| | (0.030) | (0.069) | (0.027) | (0.037) | (0.025) | (0.039) |
| Interest rate | 0.146 | -1.283*** | 0.133 | 0.088 | 0.190 | 0.229 |
| | (0.185) | (0.249) | (0.245) | (0.146) | (0.178) | (0.143) |
| Year-Industry-Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 37043 | 37043 | 37043 | 37043 | 37043 | 37043 |
| $R^2$ | 0.704 | 0.519 | 0.765 | 0.617 | 0.838 | 0.410 |

*Notes*: Dependent variables in columns (1)-(6) are the follows: log value added, log profit, log revenue, TFP(Olley-Pakes), TFP(ACF), and log labor productivity. Contrast group is processing exporters. All regressions include year-4-digit industry-province fixed effect. Standard errors clustered at the 4-digit industry level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

We find that the coefficient of the hybrid dummy is always significant and positive when different proxies for firm performance are taken into account, indicating that although hybrid exporters and processing exporters are both engaged in processing exports, hybrid exporters have significantly better performance than processing exporters in all aspects. Compared to processing exporters, hybrid

[13] The 4-digit industry classification is derived from the 2002 version of China's GB/T industry classification.

exporters report 13.7 percent higher value added, 21.6 percent higher profit, 10 percent higher revenue, 17.5 percent higher labor productivity, and an average of 10.6 percent higher TFP.[14]

Next, to provide additional evidence on the different performance of hybrid exporters with respect to purely processing exporters, we focus on export revenue and export quantity measured at a finer granularity. First, we look at the performance of hybrid exporters and processing exporters in terms of processing exports at the firm-HS6 product-destination country level. The estimated specification is:

$$Y_{ihct} = \alpha + \beta Hybrid_{ijr} + X'_{ijrt}\gamma + \eta_{jrt} + \lambda_{hct} + \epsilon_{ijrt}. \tag{1.2}$$

where $Y_{ihct}$ is the logarithm of export revenue and quantity of every HS6 product $h$ of firm $i$ exported to a given destination $c$ in year $t$. The explanatory variable (i.e., the dummy variable for hybrid exporters) and the control variables remain the same as specification (1.1). After controlling for the 4-digit industry-year-province fixed effect, we introduce here year-HS6 product-country fixed effects $\lambda_{hct}$ to consider the time-varying product-country level determinants that affect the demand for processing exports.

Then, we investigate the performance of hybrid exporters and processing exporters for processing exports at the firm-HS6 product level across destination markets. For this reason, we modify specification (1.2) as follows: the dependent variable becomes $Y_{iht}$ which is the logarithm of export revenue and quantity of each HS6 product $h$ of firm $i$ in year $t$. The explanatory variable and control variables remain the same as specification (1.2). After controlling for the 4-digit industry-year-province fixed effect, the year-HS6 product fixed effect $\lambda_{ht}$ is included to account for the time-varying global demand shocks to processing exports at the HS6 level. In all specifications, we employ the firm-level price index to deflate the revenue of processing export.

Results are reported in Table 1.3. In columns (1) and (2), we regress the logarithm of processing export revenue and quantity at firm-HS6 product-country level on the firm dummy variable. In columns (3) and (4), we regress the logarithm of export revenue and quantity at firm-HS6 product level against the firm dummy variable. We find that hybrid exporters ship a larger volume of processing exports to each export destination relative to processing exporters, and they also report

[14] Table A2 included in the Appendix reports results for specification (1.1) obtained when introducing separately year, 4-digit industry, and province fixed effects. We also report in Table A3 the results obtained comparing processing, hybrid, and non-processing (ordinary) exporters. The main conclusions of Table 1.2 are confirmed across the different specifications.

higher revenues. Hybrid firms report 17 percent higher export revenue and 10.2 percent higher export quantity than processing exporters. In the global markets, the revenue and quantity of processing exports of hybrid exporters at HS6 product level are similar to those of processing exporters. Summing up, these results imply that hybrid exporters and processing exporters report similar outcomes at the product level across markets, while hybrid exporters are able to obtain a significantly better performance in the single destination markets, suggesting that they can be more competitive than purely processing exporters when supplying the same product to the same market.

Table 1.3: Firm-product level processing export performance comparison

| | HS6 product-country level | | HS6 product level | |
|---|---|---|---|---|
| | (1) ln Export Revenue | (2) ln Export Quantity | (3) ln Export Revenue | (4) ln Export Quantity |
| Hybrid | 0.170*** | 0.102*** | 0.029 | 0.001 |
| | (0.037) | (0.039) | (0.036) | (0.033) |
| Foreign share | -0.070** | -0.120*** | 0.063** | 0.034 |
| | (0.027) | (0.031) | (0.025) | (0.027) |
| ln Age | 0.034** | -0.017 | 0.041*** | -0.001 |
| | (0.016) | (0.019) | (0.014) | (0.015) |
| ln Asset | 0.146*** | -0.016 | 0.207*** | 0.082*** |
| | (0.016) | (0.018) | (0.015) | (0.015) |
| ln Labor | 0.087*** | 0.142*** | 0.184*** | 0.215*** |
| | (0.017) | (0.025) | (0.017) | (0.018) |
| ln Subsidy | 0.008 | 0.007 | -0.003 | 0.002 |
| | (0.005) | (0.005) | (0.004) | (0.004) |
| Liquidity | 0.095*** | -0.009 | 0.047** | -0.000 |
| | (0.023) | (0.024) | (0.019) | (0.019) |
| Interest rate | -0.149 | 0.328 | -0.470*** | -0.349*** |
| | (0.145) | (0.270) | (0.181) | (0.105) |
| Year-Industry-Province FE | Y | Y | Y | Y |
| Year-HS6-Country FE | Y | Y | N | N |
| Year-HS6 FE | N | N | Y | Y |
| Observations | 726126 | 726126 | 274123 | 274123 |
| $R^2$ | 0.405 | 0.473 | 0.334 | 0.426 |

*Notes*: Columns (1)-(2) compare the export revenue and quantity of HS6 processing products sold in each country between hybrid exporters and processing exporters, and columns (3)-(4) compare the export revenue and quantity of HS6 processing products sold in global markets between hybrid and processing exporters. Dependent variables in columns (1)-(4) are the follows: log export revenue of an HS6 product in each destination, log export quantity of an HS6 product in each destination, log total export revenue of an HS6 product, and log total export quantity of an HS6 product. Contrast group is processing exporters. All regressions include year-4-digit industry-province fixed effect. Columns (1)-(2) include year-HS6 product-country fixed effect, and columns (3)-(4) include year-HS6 product fixed effect. Standard errors clustered at the HS6 product level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

## 1.5 Mechanisms explaining differences in performance

In the previous section, we documented differences in performance between the two groups of exporters engaged in processing trade, namely, hybrid exporters and processing exporters, and observed that hybrid exporters report a higher profitability and productivity than processing exporters. In this section we describe the mechanisms behind this finding.

One possible motive explaining the difference in performance is the inherent gap between processing exporters and hybrid exporters observed since their entry into the export markets. As discussed in section 1.2, processing trade benefits from a number of preferential policies, moreover, processing production only involves simple processing or assembly activities and is isolated from the core production stages such as product design, development, and marketing. Hence the investment costs and productivity thresholds to enter the foreign markets for exporters pursuing processing trade should be lower than those for non-processing exporters. The subordinate trade regimes of processing trade plausibly are associated with different entry thresholds, as well. Compared to processing with imported materials (IA), processing and assembly with supplied materials (PA) requires even lower upfront costs, since the foreign buyers provide the raw materials, components, and equipment to firms engaging in processing production. As a result, less-productive and more financially constrained firms self-select into processing trade (Dai et al., 2016; Manova and Yu, 2016). That is, the share of processing production for a firm is determined endogenously by the firm's productivity, which further leads firms reporting different shares of processing trade to report different performances.

Nevertheless, self-selection can only provide a limited explanation for the differences in performance found in this study. As in our sample, 72 percent of hybrid exporters have a processing export share of more than 50 percent, and 58 percent of hybrid exporters have a processing export share of more than 75 percent, indicating that processing exports have a dominant position in the exports of most hybrid exporters. Other factors than self-selection shall then explain such striking differences in performance among firms in our sample.

The production choices of firms, such as the use of imported materials, or their different requirements for inputs' quality, might also be responsible for the different performance of hybrid exporters with respect to processing exporters. Therefore, we will focus on production behaviors of these two groups of exporters engaged in processing trade by analyzing the *ratio of domestic value added in exports to gross exports* (DVAR).

### 1.5.1 Domestic value added ratio of processing exports

#### 1.5.1.1 Measuring DVAR

Domestic value added (DVA) in exports measures the total, domestically created, value contained in exports. According to Kee and Tang (2016), the domestic value added in exports ($DVA_i$) of firm $i$ can be decomposed into the following components: profits ($\pi_i$), wages ($W_i$), costs of capital ($K_i$), and costs of domestic inputs ($M_i^D$):

$$DVA_i \equiv \pi_i + W_i + K_i + M_i^D. \tag{1.3}$$

From equation (1.3), one can see that the increase of DVA may come from the increment of any component included in the equation above. If only the expenditures on labor, capital or intermediate inputs are driving the growth of DVA, a higher DVAR does not mean an improvement in firm performance but, actually, a decline in competitiveness. On the contrary, if saved expenditures coming from such as the substitution between domestic and imported inputs lead to increasing retained profits, then DVAR is positively correlated with firm performance.[15] Kee and Tang (2016) observe that China's domestic content in exports increases from 65 to 70 percent in the period 2000-2007, mainly driven by the considerable growth of DVAR of processing exports, which increases from 46 percent in 2000 to 55 percent in 2007. The main force behind the increment is that processing exporters substitute imported inputs with domestic inputs on a large scale, as input tariffs reductions and the inward FDI stimulate the development of domestic inputs and increase the prices of imported inputs relative to domestic inputs. However, Kee and Tang (2016) do not characterize firm level DVAR conditional on the depth of the firm's participation in processing exports. Therefore, in this section, we first examine the DVAR of processing exports for hybrid exporters and processing ex-

[15] Domestic inputs in our database include materials sourced from other firms and inputs produced inside vertically integrated firms. We cannot differentiate the two sorts of inputs. Vertical integration affects firms' decisions of input sources, resulting in fewer external purchases and more within-firm transactions which are counted as the value generated by the firm and contribute to higher value-added. We therefore follow Adelman (1955), Holmes (1999), and Du et al. (2012) and use the ratio of value added to sales as the measure of the degree of vertical integration. It is worth mentioning that Du et al. (2012) and Holmes (1999) measure value added with the sales less purchased inputs while we employ the information of value added recorded in ASIF. Our check suggests no significant difference in the ratio between hybrid and pure processing exporters, indicating a similar degree of vertical integration among them, as shown in Table A4.

porters, and then determine whether DVAR can explain the different performance observed in section 1.4.[16]

Assume firm $i$ is involved in processing export, then it imports some materials ($IMP_i$) and exports all the processed products ($EXP_i$) to foreign markets.[17] Considering that domestic inputs employed for the production of exported products may contain purely domestic content ($PM_i^D$) and foreign content ($m_i^F$), and the employed imported inputs may contain foreign content ($PM_i^F$) and domestic content ($m_i^D$), the adjusted cost of domestic inputs is:

$$Adj\_M_i^D \equiv PM_i^D - m_i^F + m_i^D. \tag{1.4}$$

Equation (1.3) can be rewritten as :

$$DVA_i \equiv \pi_i + W_i + K_i + PM_i^D - m_i^F + m_i^D, \tag{1.5}$$

and firm $i$'s exports and DVA can be expressed as

$$EXP_i = DVA_i + IMP_i + m_i^F - m_i^D, \tag{1.6}$$

$$DVA_i = (EXP_i - IMP_i) + (m_i^D - m_i^F). \tag{1.7}$$

Since the domestic content embodied in imported inputs is close to 0 for Chinese processing exports (Koopman et al., 2012; Wang et al., 2013), the DVAR of firm $i$'s processing exports equal to

$$DVAR_i \equiv \frac{DVA_i}{EXP_i} = 1 - \frac{IMP_i}{EXP_i} - \frac{m_i^F}{EXP_i}. \tag{1.8}$$

[16] In this study, we only focus on the DVAR of processing exports, hence DVAR refers to the DVAR of processing exports when it comes to hybrid exporters.

[17] We use imported materials as firm $i$'s imports in the computation of DVAR, as the capital and material imports for processing trade are separately recorded in CCTS except for year 2007, which collectively reports the imported equipment and materials. Hence proxying imported materials by the collectively reported imports will bias downward the estimation of DVAR in 2007. If hybrid exporters and processing exporters import different shares of equipment, it will lead to the fact that the DVAR of the two is underestimated to different extents. We discuss this issue in section 1.6.1 by comparing the difference of imported processing equipment of the two firm groups and find that, hybrid exporters import more equipment in the period 2000-2006 than processing exporters. This result shows that our estimate for the DVAR of hybrid exporters in 2007 is biased downwards, yet, the DVAR of hybrid exporters during the period 2000-2007 is still higher than that of processing exporters, as we will show in this section. Given the results, adjusting equipment imports in 2007 would only strengthen the point that hybrid exporters achieve higher DVAR. Therefore, we keep the data for 2007 in the analysis. Nevertheless, we estimate the same specifications excluding observations for the year 2007 as robustness checks and report results in Table A5 to Table A7.

After controlling for $IMP_i$ and $EXP_i$, we use the industry-level estimates of $m^F$ provided by Kee and Tang (2016) to adjust the foreign content embodied in domestic inputs and estimate the DVAR of processing exports for each firm.

Some exporters doing processing trade indirectly import inputs from other domestic exporters engaged in processing production, the purchasers of such transactions are referred as excessive exporters, and the sellers are referred as excessive importers. However, these transactions are unrevealed in databases, and ignoring these transactions leads to the DVAR of excessive exporters being overestimated and the DVAR of excessive importers being underestimated or even negative, thus generating outliers. To get rid of these biases, we draw on the method developed by Kee and Tang (2016) and identify excessive importers as firms that import more processing imports than their total costs of intermediate inputs recorded in ASIF. Regarding excessive exporters, since processing imports are exempt from import tariffs whereas ordinary imports are not, ordinary exporters rely less on imported inputs. That is, the DVAR of ordinary exports should be higher than the DVAR of processing exports in the same industry. Therefore, we use the 25th percentile of DVAR of ordinary exports as the upper bound of DVAR of processing exports within the industry, and then identify exporters engaged in processing trade whose DVAR exceeds the upper bound as excessive exporters. We will use combined filters on excessive importers and excessive exporters in the following analysis to eliminate outliers in our estimation sample.

Since there are several firms operating in multiple industries among exporters pursuing processing trade, we calculate the firm-level average DVAR weighted by the share of processing exports in each industry. The yearly national DVAR of processing exports aggregated from the DVAR of single-industry firms, computed using data from our sample, is reported in Figure A1 of the Appendix and it is closely comparable to the result of Kee and Tang (2016).

#### 1.5.1.2 Relation between DVAR and firm performance

To assess differences in DVAR between processing exporters and hybrid exporters, we estimate the following specification:

$$DVAR_{ijrt} = \alpha + \beta Hybrid_{ijr} + X'_{ijrt}\gamma + \eta_{jrt} + \epsilon_{ijrt}, \tag{1.9}$$

where $DVAR_{ijrt}$ is the DVAR of processing exports of firm $i$ in year $t$, $Hybrid_{ijr}$ is the dummy variable for hybrid exporters. $X_{ijrt}$ is a series of variables that control for the characteristics of the firm, as employed in specification (1.1). We take into account the influence of unobservable time-varying changes using industry-province-year fixed effect.

Table 1.4 reports the results. In column 1, we exclude excessive importers, and in column 2, we exclude both excessive importers and excessive exporters. In both columns, we regress DVAR on the dummy variable for hybrid firms and control for the firm's size, age, ownership structure, financial constraints, and subsidies. We find that, after dropping outliers with different filters, the coefficients of the dummy are positive and significant, indicating that hybrid exporters have higher domestic value added. The sorting pattern of DVAR between the two groups of exporters is consistent with their performance outcomes.

Table 1.4: A comparison in DVAR

| (1) | (1)<br>DVAR | (2)<br>DVAR |
|---|---|---|
| Hybrid | 0.020*** | 0.024*** |
| | (0.007) | (0.006) |
| Foreign share | -0.022*** | -0.007 |
| | (0.008) | (0.008) |
| ln Age | 0.004* | 0.009*** |
| | (0.002) | (0.002) |
| ln Asset | -0.014*** | -0.010** |
| | (0.005) | (0.004) |
| ln Labor | 0.015*** | 0.017*** |
| | (0.004) | (0.003) |
| ln Subsidy | 0.002** | 0.001 |
| | (0.001) | (0.001) |
| Liquidity | 0.005 | 0.004 |
| | (0.005) | (0.004) |
| Interest rate | 0.013 | 0.002 |
| | (0.014) | (0.010) |
| Year-Industry-Province FE | Y | Y |
| Observations | 37844 | 32051 |
| $R^2$ | 0.261 | 0.259 |

*Notes*: Dependent variables in columns (1)-(2) are the DVAR of processing exports. In column (1), excessive importers are excluded, and in column (2), both excessive importers and exporters are excluded. Contrast group is processing exporters. All regressions include year-4-digit industry-province fixed effect. Standard errors clustered at the 4-digit industry level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

As discussed above, the relationship between DVAR and firm performance depends on whether the firm can retain more profits from a higher DVAR. Therefore, we now examine the contribution of DVAR to the performance of hybrid exporters and processing exporters. To this end, we estimate the following specification:

$$Y_{ijrt} = \alpha + \beta DVAR_{ijrt} + X'_{ijrt}\gamma + \delta_i + \zeta_t + \epsilon_{ijrt}, \tag{1.10}$$

where $Y_{ijrt}$ is the indicator of firm profitability and productivity, as employed in specification (1.1). $DVAR_{ijrt}$ is the DVAR of processing exports of the firm, and $X_{ijrt}$ denotes the firm level control variables. $\delta_i$ is the firm fixed effect, introduced to control for firm-level unknowns. $\zeta_t$ is the year fixed effect that controls unobservable factors in each sample year. We separately estimate specification (1.10) for hybrid exporters and processing exporters.

Results of hybrid exporters and processing exporters are respectively reported in Panel A and Panel B in Table 1.5. In columns (1)-(3), we regress the logarithm of value added, profit, and revenue on DVAR. In columns (4)-(6), we employ $TFP(OP)$, $TFP(ACF)$, and logarithm of labor productivity as outcome variables. In all columns, we control for the year and firm fixed effects. We find that DVAR plays different roles in the performance of hybrid exporters and processing exporters. Overall, the DVAR of processing exports of hybrid exporters is positively correlated with firm performance. An increase in DVAR by one unit is associated with an increase in value added by 9.0 percent, profit increase by 17.6 percent, and labor productivity increase by 10.3 percent, and has no significant effect on revenue and TFP. On the contrary, DVAR plays no role in affecting all performance indicators for purely processing exporters. This result shows that the higher DVAR of hybrid exporters is not driven by rising costs, it is due to the use of more cost-effective domestic inputs to substitute imported inputs, thus leading to higher earnings and better outcomes. Compared to hybrid exporters, processing exporters' substitution between domestic and imported inputs is lower and does not lead to higher earnings. Therefore, their DVAR is lower and the impact of DVAR on performance is basically null.

Table 1.5: The role of DVAR in firm performance

| | (1)<br>ln VA | (2)<br>ln Profit | (3)<br>ln Revenue | (4)<br>TFP(OP) | (5)<br>TFP(ACF) | (6)<br>ln LabPro |
|---|---|---|---|---|---|---|
| *Panel A: Sample of Hybrid Exporters* | | | | | | |
| DVAR | 0.090** | 0.176** | -0.007 | 0.063 | -0.038 | 0.103** |
| | (0.045) | (0.084) | (0.037) | (0.049) | (0.028) | (0.046) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | Y | Y | Y | Y | Y |
| Observations | 16066 | 16066 | 16066 | 16066 | 16066 | 16066 |
| $R^2$ | 0.879 | 0.784 | 0.936 | 0.822 | 0.924 | 0.769 |
| | (1)<br>lnVA | (2)<br>lnProfit | (3)<br>lnRevenue | (4)<br>TFP(OP) | (5)<br>TFP(ACF) | (6)<br>lnLabPro |
| *Panel B: Sample of Processing Exporters* | | | | | | |
| DVAR | 0.016 | 0.168 | -0.048 | 0.025 | -0.038 | -0.018 |
| | (0.084) | (0.144) | (0.072) | (0.092) | (0.049) | (0.086) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | Y | Y | Y | Y | Y |
| Observations | 6563 | 6563 | 6563 | 6563 | 6563 | 6563 |
| $R^2$ | 0.861 | 0.749 | 0.939 | 0.805 | 0.923 | 0.757 |

*Notes*: Dependent variables in columns (1)-(6) are the follows: log value added, log profit, log revenue, TFP(Olley-Pakes), TFP(ACF), and log labor productivity. Both excessive importers and excessive exporters are excluded. All regressions control for firm size, age, ownership structure, financial constraints, and subsidies, and include year and firm fixed effects. Standard errors clustered at the 4-digit industry level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

#### 1.5.1.3 The driving forces behind the higher DVAR

The analysis discussed above suggests that the performance of exporters participating in processing trade is related to the extent to which they use domestic inputs to replace imported inputs in processing production. The point is then understanding the reason why hybrid firms rely more on domestic inputs than processing firms. Kee and Tang (2016) show that the DVAR of a firm depends on the relative price of imported inputs to domestic inputs (referred to as the relative price, for concision), and the relative price is affected by domestic upstream varieties of products and exchange rates. Therefore, factors influencing domestic upstream varieties will indirectly affect a firm's DVAR. The following determinants of domestic upstream varieties are proposed by Kee and Tang (2016): input tariffs facing domestic input suppliers, own-industry FDI inflows, and exchange rates, the price in foreign-currency of a Chinese Yuan.

In addition, we argue that the degree of upstream market concentration may be another determinant, as market competition largely affects product prices. We summarize the possible transmission mechanisms of various factors affecting the relative price based on the arguments of Kee and Tang (2016) as follows.

—*Own-industry FDI.* A larger amount of own-industry FDI generates higher demand for domestic upstream materials, thereby increases the number of domestic upstream varieties. We further argue that the expanding downstream demand may attract more firms to enter the upstream market, thus stimulating competition in the industry.

—*Upstream input tariffs reductions.* Lower upstream input tariffs lead to more varieties of upstream products, thereby affecting the relative price. Besides, we believe that reductions in upstream input tariffs enable upstream suppliers to import raw materials at more favorable prices and reduce production costs, making domestic inputs cheaper and thus directly affecting the relative price. The general cutback in the production costs of suppliers helps strengthen upstream market competition and leads to more competitive prices further.

—*Exchange rates.* A higher exchange rate (a Yuan appreciation) refers to the stronger purchasing power of the Chinese Yuan for foreign products, as it decreases the price in Yuan of imported materials. Exchange rates thus change the relative price directly and also indirectly by affecting domestic upstream varieties. In addition, we argue that as large firms have more bargaining power in international trade than small firms, large upstream suppliers can benefit more from appreciating exchange rates. They may import more raw materials and obtain stronger market power leading to higher market concentration.

—*Upstream concentration.* We believe that an exacerbated degree of upstream concentration increases the price of domestic upstream products and lowers the relative price.

To sum up, we argue that more domestic upstream varieties, lower exchange rates, reduced upstream input tariffs, and mitigated upstream concentration should increase the relative price of imported inputs and result in higher DVAR.

In view of the different levels of DVAR between hybrid exporters and processing exporters, we believe that the heterogeneous selections in input sources stem from the fact that they face different relative prices. Therefore, we next examine this by estimating the following chained specifications and explore the reasons behind the different relative prices,

$$\boldsymbol{\Delta} DVAR_{ijrt} = \alpha^1 + \beta_P^1 \, \boldsymbol{\Delta} Pr_{ijrt} + \lambda_{jrt}^1 + \epsilon_{ijrt}^1, \tag{1.11}$$

$$\begin{aligned} \boldsymbol{\Delta} Pr_{ijrt} =& \alpha^2 + \beta_T^2 \, \boldsymbol{\Delta} Taf_{ijrt} + \beta_V^2 \, \boldsymbol{\Delta} Vd_{ijrt} + \beta_U^2 \, \boldsymbol{\Delta} Up_{ijrt} \\ &+ \beta_E^2 \, \boldsymbol{\Delta} Ex_{ijrt} + \beta_H^2 \, Hybrid_{ijr} + \lambda_{jrt}^2 + \epsilon_{ijrt}^2, \end{aligned} \tag{1.12}$$

$$\begin{aligned}\boldsymbol{\Delta} Vd_{ijrt} =& \alpha^3 + \beta_T^3\, \boldsymbol{\Delta} Taf_{ijrt} + \beta_E^3\, \boldsymbol{\Delta} Ex_{ijrt} + \beta_F^3\, \boldsymbol{\Delta} FDI_{ijrt} \\ &+ \beta_H^3\, Hybrid_{ijr} + \lambda_{jrt}^3 + \epsilon_{ijrt}^3, \end{aligned} \tag{1.13}$$

$$\begin{aligned}\boldsymbol{\Delta} Up_{ijrt} =& \alpha^4 + \beta_T^4\, \boldsymbol{\Delta} Taf_{ijrt} + \beta_E^4\, \boldsymbol{\Delta} Ex_{ijrt} + \beta_F^4\, \boldsymbol{\Delta} FDI_{ijrt} \\ &+ \beta_H^4\, Hybrid_{ijr} + \lambda_{jrt}^4 + \epsilon_{ijrt}^4, \end{aligned} \tag{1.14}$$

$$\boldsymbol{\Delta} Taf_{ijrt} = \alpha^5 + \beta_H^5\, Hybrid_{ijr} + \lambda_{jrt}^5 + \epsilon_{ijrt}^5, \tag{1.15}$$

$$\boldsymbol{\Delta} FDI_{ijrt} = \alpha^6 + \beta_H^6\, Hybrid_{ijr} + \lambda_{jrt}^6 + \epsilon_{ijrt}^6. \tag{1.16}$$

Except for the firm dummy variable $Hybrid_{ijr}$, the dependent and independent variables in specifications (1.11)-(1.16) are the change in the variable of interest for firm $i$ in year $t$ relative to the value in the first year that firm $i$ enters the sample. Among them, $\boldsymbol{\Delta} Pr_{ijrt}$ is the change of the relative price of imported inputs facing firm $i$, $\boldsymbol{\Delta} Taf_{ijrt}$ is the change of upstream input tariffs, $\boldsymbol{\Delta} Vd_{ijrt}$ is the change of domestic upstream varieties, $\boldsymbol{\Delta} Ex_{ijrt}$ is the change of exchange rates, $\boldsymbol{\Delta} FDI_{ijrt}$ is the change of own-industry FDI, and $\boldsymbol{\Delta} Up_{ijrt}$ is the change of upstream concentration. We use the firm production data provided by ASIF to calculate the Herfindal index for each 3-digit CIC industry, combined with the consumption coefficients provided by China's Input-Output Table in 2002, then the weighted averages of Herfindal indices in the upstream industries are used as the proxy for the upstream concentration ($Up_{ijrt}$) faced by firms in each 3-digit CIC industry. We employ data for $Pr$, $Vd$, $Taf$, $FDI$, and $Ex$ (in logarithm) at UN sector level provided in Kee and Tang (2016), and calculate the firm level weighted average variables with the processing export shares across sectors of the firm.[18] The terms $\lambda_{jrt}^j$ and $\epsilon_{ijrt}^j, 1 \leq j \leq 6$, denote the year-2-digit industry-province fixed effect and error terms in specifications (1.11)-(1.16), respectively.

This set of chained regressions can be split into three stages. In the first stage, we explain the changes in DVAR by the changes in the relative price of imported inputs faced by firms engaged in processing production with specification

[18] These sectors are: (1) live animals (HS2 codes between 1 and 5); (2) vegetables (6-14); (3) animal or vegetable oil (15); (4) beverage and spirit (16-24); (5) mineral products (25-27); (6) chemical products (28-38); (7) plastics and rubber (39-40); (8) raw hides and skins (41-43); (9) wood and articles (44-46); (10) pulp of wood (47-49); (11) textiles (50-63); (12) footwear and headgear, etc. (64-67); (13) stone, plaster, cement, etc. (68-70); (14) precious metals (71); (15) base metals (72-83); (16) machinery, mechanic, electronic equipment (84-85); (17) vehicles and aircraft (86-89); (18) optical, photographic, etc. (90-92); (20) miscellaneous manufacturing (94-96).

(1.11), followed by specification (1.12) by which we explore how upstream input tariffs reductions, the increase in domestic upstream varieties, lower upstream market concentration, and rising exchange rates affect the relative price. After controlling for these factors, we examine whether there are other underlying factors that may cause different relative prices facing hybrid exporters and processing exporters. In the second stage, we examine whether the changes in upstream input tariffs, exchange rates, and own-industry FDI affect the relative price facing each firm through influencing domestic upstream varieties and upstream market concentration, with specifications (1.13) and (1.14). After controlling for the aforesaid factors, we examine whether there are other determinants that may lead to different domestic upstream varieties and upstream market concentration facing hybrid and processing exporters. In the last stage, with specifications (1.15) and (1.16) we examine whether hybrid and processing exporters face different upstream tariff reductions and own-industry FDI, which may directly and indirectly determine the relative price of imported inputs.

Results reported in Table 1.6 certify our inferences. Column (1) shows that variations in the imported inputs' relative price change the DVAR of processing exports. Column (2) suggests that greater upstream input tariffs reductions, more domestic upstream varieties, intensified upstream market competition, and a depreciation of the Chinese Yuan increase the relative price, and thus lead to higher DVAR. The firm dummy's coefficient is insignificant, indicating that after controlling for these factors, there are no omitted variables that contribute to a higher relative price specifically related to hybrid exporters. Column (3) indicates that more own-industry FDI inflows result in increased domestic upstream varieties. The inconsistency with expectations is that upstream input tariffs reductions and changes in exchange rates facing firms engaged in processing production do not seem to significantly impact on domestic upstream varieties that firms have access to. Column (4) conveys that upstream input tariffs reductions and continuous own-industry FDI inflows help stimulating upstream market competition. In contrast, higher exchange rates raise the upstream concentration. Columns (5) and (6) indicate that hybrid exporters benefit from greater upstream input tariffs reductions and a larger volume of own-industry FDI relative to processing exporters.

These findings demonstrate that hybrid exporters more substitute imported inputs with domestic inputs and achieve greater DVAR because their own industries receive more FDI inflows and benefit from larger reductions in upstream input tariffs. On the one hand, abundant FDI resources and substantial reductions in upstream input tariffs help alleviating upstream market concentration faced by

Table 1.6: Driving forces of differentiated DVAR

| | (1) ΔDVAR | (2) ΔRelative price | (3) ΔDomestic upstream varieties | (4) ΔUpstream market concentration | (5) ΔUpstream input tariff | (6) ΔFDI |
|---|---|---|---|---|---|---|
| ΔRelative price | 0.177*** | | | | | |
| | (0.018) | | | | | |
| ΔUpstream input tariff | | -0.445*** | 0.003 | 0.343*** | | |
| | | (0.019) | (0.018) | (0.040) | | |
| ΔDomestic upstream varieties | | 0.087*** | | | | |
| | | (0.021) | | | | |
| ΔUpstream market concentration | | -0.062*** | | | | |
| | | (0.014) | | | | |
| ΔExchange rates | | -0.889*** | 0.018 | 0.753*** | | |
| | | (0.032) | (0.025) | (0.156) | | |
| ΔFDI | | | 0.043*** | -0.047* | | |
| | | | (0.010) | (0.025) | | |
| Hybrid | | 0.001 | 0.000 | 0.002 | -0.020*** | 0.037*** |
| | | (0.002) | (0.001) | (0.004) | (0.005) | (0.009) |
| Year-Industry-Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 36437 | 36437 | 36437 | 36437 | 36437 | 36437 |
| $R^2$ | 0.077 | 0.805 | 0.186 | 0.448 | 0.208 | 0.289 |

*Notes*: Studied variables are the change of the variable of interest in each year relative to the value in the first year that this firm enters the sample. Dependent variables in columns (1)-(6) are the change of: DVAR, log relative price, log domestic upstream varieties, log upstream market concentration, log upstream input tariffs, and log own-industry FDI. Both excessive importers and excessive exporters are excluded. All regressions include year-2-digit industry-province fixed effect. Standard errors clustered at the 4-digit industry level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

hybrid exporters and lead their domestic input prices to move closer to competitive prices; on the other hand, FDI inflows stimulate the enrichment of domestic upstream varieties. These two aspects indirectly lead hybrid exporters to employ more domestic inputs in processing production. The upstream input tariffs for suppliers of hybrid exporters drop more, leading to cheaper domestic inputs, thus encouraging hybrid exporters to use more domestic materials and obtain higher profits.

### 1.5.2 Production specialization: quality and variety

An implication from the DVAR framework is that firm performance depends on the firm's ability to create retained profits in production. In addition to the impact of production-side improvements such as the adjustment of input sources, the ability of a firm to obtain higher profits is also subject to the competitiveness of its products, which might be determined by product quality. Therefore, we consider product quality as an additional determinant for the performance of hybrid and processing exporters.

An intuitive indicator for measuring product quality is the unit price since price should be proportional to product quality (Hallak, 2006). However, the price of a product also depends on other factors, and in particular on firm productivity. Therefore, we estimate product quality following the procedure proposed by Khandelwal et al. (2013). Assume the utility function of the representative consumer in the export market is a CES function which incorporates the horizontal and vertical differentiation of products, the demand system ($q_c(h)$) derived from the utility function for a given variety ($h$) is determined by product quality ($\theta_c(h)$), unit price ($p_c(h)$), elasticity of substitution between varieties ($\sigma$), price index ($P_c$), and income ($I_c$) in the export market,

$$q_c(h) = \theta_c^{\sigma-1}(h)\, p_c^{-\sigma}(h)\, P_c^{\sigma-1}\, I_c. \tag{1.17}$$

After taking the logarithm of equation (1.17), the product quality of each firm-product-country-year pair is obtained by estimating the residual of the following equation:

$$ln\, q_{ihct} + \sigma ln\, p_{ihct} = \alpha_h + \alpha_{ct} + \epsilon_{ihct}, \tag{1.18}$$

where $\alpha_h$ is the product fixed effect, introduced to take into account different product-level characteristics. $\alpha_{ct}$ is the country-year fixed effect controlling for the time-varying demand shocks that come from income and local price index within an export market. Hence the estimated product quality is:

$$ln\, \hat{\theta} = \hat{\epsilon}_{ihct}/(\sigma - 1). \tag{1.19}$$

The quality-adjusted prices therefore are,

$$ln\, Adj\_Price_{ihct} = ln\, p_{ihct} - ln\, \hat{\theta}. \tag{1.20}$$

We estimate the quality and quality-adjusted price of each HS6 processing product shipped by a firm to a specific destination market in a given year, based on the information of product transaction level unit price, export quantity, and destination market provided by CCTS, as well as the data of country-sector level elasticity of substitution provided by Broda et al. (2006). Using the same method, we also estimate import quality and quality-adjusted price at the firm-product-country-year level, while the elasticity of substitution employed in this case is the one referring to HS 3-digit sectors in China. The quality estimates are truncated at the 1st and 99th percentiles to eliminate the influence of outliers. It is noteworthy that Broda et al. (2006) report the elasticity of substitution for HS3 products in 73 countries and regions around the globe. Therefore, about 15 percent of processing exports and 1.5 percent of processing imports in our sample are not included in these estimations. Since the country list covers most of the major trading countries, which are also the main importing countries of China's processing exports, the trimming procedure has a minor impact on the export side. The covered proportions of processing exports (imports) of hybrid exporters and processing exporters are close, which are 83.8 percent (98.1 percent) and 86.4 percent (98.7 percent), respectively. Therefore, the trimming of data shall exert similar effects on hybrid exporters and processing exporters, and shall not cause severe deviations in the comparison of the two.

We also count the number of varieties exported by the firm, considering the amount of different HS6 products exported by each firm to each export market in a given year. To examine the quality and varieties of processing exports and imports of hybrid exporters and processing exporters, we estimate the following specification:

$$Z_{ihct} = \alpha + \beta Hybrid_{ijr} + X'_{ijrt}\gamma + \eta_{jrt} + \mu_{hct} + \epsilon_{ihct}, \tag{1.21}$$

where $Z_{ihct}$ is the logarithm of unit price, quality, and quality-adjusted price of processing exports and imports at country-product level of firm $i$ in year $t$. When considering product variety, $Z_{ihct}$ is replaced by $Z_{ict}$ which is the number of varieties at firm-country-year level. $Hybrid_{ijr}$ is the firm dummy standing for hybrid exporters. $X_{ijrt}$ is the vector of firm level control variables including the ones employed in the previous specifications, as well as firm TFP (calculated by following Olley and Pakes, 1996) and logarithm of revenue, as productivity and revenue may affect the firm's choice of quality and product varieties. $\eta_{jrt}$ is the 4-digit industry-province-year fixed effect. When product price and quality are investigated, the product-country-year fixed effect, $\mu_{hct}$, is introduced to control for time-varying unobservable shocks at the product-country level. When it comes to product varieties, we use $\tau_{ct}$, the country-year fixed effect to replace $\mu_{hct}$ and control for unknowns in each country varying over time.

Results are reported in Table 1.7. In columns (1)-(2), we consider the unit price of each year-country-HS6 product pair, and regress the logarithm of the unit value of imports and exports on the firm dummy, respectively. In columns (3)-(4)

and (5)-(6), we respectively consider the quality and the quality-adjusted price of each year-country-product pair. In columns (7)-(8), the firm's export and import varieties of HS6 products of each country-year pair are considered. We find that the coefficients of the hybrid dummy are significant and positive when unit price is taken into account, indicating that hybrid exporters export and import products of higher prices than processing exporters. Hybrid exporters and processing exporters import products of similar quality, nevertheless, hybrid exporters ship processed products of higher quality than purely processing exporters. When taking product quality into account, hybrid exporters still import inputs of higher price but export products of lower price with respect to purely processing exporters. Hybrid exporters import and export fewer varieties of products with respect to processing exporters.

Table 1.7: Price, quality, and variety of processing exports and imports

| | ln Price | | ln Quality | | ln Adj_Price | | ln Variety | |
|---|---|---|---|---|---|---|---|---|
| | (1) Imports | (2) Exports | (3) Imports | (4) Exports | (5) Imports | (6) Exports | (7) Imports | (8) Exports |
| Hybrid | 0.094*** | 0.073*** | 0.030 | 0.214*** | 0.068*** | -0.130*** | -0.098*** | -0.070*** |
| | (0.011) | (0.026) | (0.022) | (0.040) | (0.018) | (0.028) | (0.021) | (0.006) |
| ln Revenue | 0.143*** | 0.196*** | 0.399*** | 0.414*** | -0.271*** | -0.221*** | 0.090*** | 0.020*** |
| | (0.008) | (0.019) | (0.030) | (0.031) | (0.028) | (0.019) | (0.017) | (0.003) |
| TFP(OP) | -0.007** | -0.027*** | -0.009* | -0.023* | 0.004 | -0.004 | -0.011*** | -0.005*** |
| | (0.003) | (0.007) | (0.005) | (0.013) | (0.004) | (0.011) | (0.004) | (0.001) |
| Foreign share | -0.009 | 0.046** | -0.014 | -0.035 | 0.009 | 0.067*** | 0.191*** | 0.127*** |
| | (0.011) | (0.020) | (0.019) | (0.030) | (0.012) | (0.021) | (0.037) | (0.013) |
| ln Age | -0.068*** | -0.030** | -0.120*** | -0.055*** | 0.055*** | 0.025** | 0.029* | 0.042*** |
| | (0.007) | (0.012) | (0.012) | (0.018) | (0.008) | (0.012) | (0.015) | (0.006) |
| ln Asset | 0.107*** | 0.053*** | 0.115*** | 0.018 | -0.008 | 0.035*** | 0.003 | 0.008* |
| | (0.006) | (0.009) | (0.012) | (0.016) | (0.011) | (0.013) | (0.016) | (0.005) |
| ln Labor | -0.121*** | -0.105*** | -0.174*** | -0.087*** | 0.059*** | -0.015 | 0.087*** | 0.068*** |
| | (0.010) | (0.028) | (0.016) | (0.032) | (0.010) | (0.016) | (0.021) | (0.009) |
| ln Subsidy | -0.001 | -0.003 | -0.008*** | -0.007 | 0.006*** | 0.003 | -0.016*** | -0.007*** |
| | (0.002) | (0.003) | (0.003) | (0.005) | (0.002) | (0.004) | (0.003) | (0.001) |
| Liquidity | 0.070*** | 0.085*** | 0.081*** | 0.162*** | -0.014 | -0.073*** | -0.010 | 0.008 |
| | (0.008) | (0.017) | (0.015) | (0.029) | (0.010) | (0.022) | (0.011) | (0.006) |
| Interest rate | -0.113** | -0.434* | -0.353*** | -0.668*** | 0.246*** | 0.328** | -0.236* | -0.442** |
| | (0.046) | (0.230) | (0.076) | (0.258) | (0.054) | (0.139) | (0.123) | (0.178) |
| Year-Industry-Province FE | Y | Y | Y | Y | Y | Y | Y | Y |
| Year-Country-HS6 FE | Y | Y | Y | Y | Y | Y | N | N |
| Year-Country FE | N | N | N | N | N | N | Y | Y |
| Observations | 1441642 | 710592 | 1400894 | 555588 | 1400894 | 555588 | 272247 | 401388 |
| $R^2$ | 0.772 | 0.749 | 0.286 | 0.803 | 0.580 | 0.858 | 0.313 | 0.320 |

*Notes*: Dependent variables in columns (1)-(6) are at the country-HS6 product-year level and the follows: log unit price of imports and exports, log quality of imports and exports, log quality-adjusted unit price of imports and exports. Dependent variables in columns (7)-(8) are the log varieties of HS6 products of imports from each importing source and exports sold in each export market, respectively. All regressions include year-4-digit industry-province fixed effect. Columns (1)-(6) include year-country-HS6 product fixed effect, and columns (7)-(8) include year-country fixed effect. Standard errors clustered at HS6 product level in columns (1)-(6), and at country level in columns (7)-(8) are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

An intriguing finding arises from the horizontal comparisons between the price difference and the quality difference between imports and exports. The price difference of imports and exports between hybrid exporters and processing exporters are of similar magnitudes: on average, hybrid firms' imports and exports are respectively 9.4 percent and 7.3 percent more expensive than these of processing exporters. No significant difference is found in import quality. However, the difference in export quality between the two groups of firms is far larger, as the quality of the exports from hybrid firms is on average 21.4 percent higher than that of purely processing exporters. This finding is reinforced by the difference of quality-adjusted prices between the two: hybrid firms' imports are 6.8 percent more costly than those of processing exporters, but their exports are 13.0 percent cheaper than the latter's, suggesting that the higher nominal prices of exports from hybrid firms are mostly due to quality. Combining these findings together we obtain a clear description of the traits of hybrid exporters in terms of product quality and pricing: hybrid exporters are more specialized and productive in the processing production of a narrower range of products. Hybrid exporters sell products of higher quality yet at a moderate-price to foreign markets relative to processing exporters, which means they don't pass on more price to consumers, and charge even lower prices given the quality. This "quality at competitive prices" strategy results in hybrid exporters gaining relevant market shares in the respective destination markets compared to processing exporters, as described in Table 1.3, and eventually brings about the superior performance of hybrid exporters.

Overall, our findings show that hybrid exporters report higher productivity and supply goods of higher quality at modestly higher prices to the international markets. This result is consistent with findings in Johnson (2012), Kugler and Verhoogen (2012), and Manova and Zhang (2012) which observe a positive correlation between firm productivity and output quality, as modeled in Feenstra and Romalis (2014). Even if more productive firms are more efficient at employing any type of inputs, they optimally choose to supply high-quality goods. When quality quickly augments in productivity, then we observe higher marginal costs and prices as more productive exporters rely on high-quality inputs which are more costly. Indeed, Hallak and Sivadasan (2013) suggest that higher output quality is associated with costly inputs and skilled labor, and with the adoption of capital-intensive production techniques. On the contrary, when the marginal cost does not sufficiently increase in quality, the standard predictions of the Melitz (2003) model on the negative relation between prices and productivity are confirmed.

## 1.6 Robustness checks

### 1.6.1 On the substitution between imported inputs and domestic inputs

The analysis discussed in section 1.5.1 shows that hybrid exporters substitute more imported inputs with domestic inputs in processing production, thereby achieve higher profits and improved performance. Here we investigate this finding from two different perspectives. First, if hybrid exporters use more domestic inputs, imported inputs should account for a smaller share in their total intermediate inputs used in processing production. But a thorny issue is that we do not have information on how firms allocate intermediate inputs between the production of products for ordinary exports, processing exports, and domestic sales. Moreover, since ASIF and CCTS employ different currencies to define variables in the databases (RMB and US dollars, respectively), using the values of exports in CCTS and total sales in ASIF may lead to biases or data frictions due to currency conversion. Therefore, we calculate the share of processing exports accounting for the firm's total exports, by which we infer the intermediate inputs employed for processing production. This approach relies on the assumption that the firm's allocation of intermediate inputs is proportional to the export composition. Although this assumption may partially ignore some implications of firm heterogeneity, it appears to be a reasonable one conditional on the current data availability. We also discuss the alternative method in Table A8, included in the Appendix, using the share of processing exports in firm's total sales (available from ASIF) as the reference to infer the allocation of intermediate inputs.

Second, as discussed in section 1.2, the two subordinate trade regimes of processing trade, processing with imported materials (IA), and processing and assembly with supplied materials (PA), may demand domestic inputs to varying degrees. Under the PA trade regime, foreign buyers directly provide raw and auxiliary materials for production, so firms may demand less domestic inputs. Under the IA trade regime, firms need to import raw materials from foreign markets on their own, hence have more room for the selection of input sources. Therefore, one reason for the differentiated DVAR may be that hybrid exporters and processing exporters are mainly engaged in different subordinate regimes of processing trade. We calculate the share of exports and imports under the IA trade regime in total processing exports and imports of each firm to proxy the allocation of firm's production between IA and PA trade regimes.

We make slight changes to specification (1.1) to examine these two inferences. We replace the dependent variables with $m^F$ *ratio*, *IA_exports*, and *IA_imports*. $m^F$ *ratio* is the share of imported inputs in total intermediate inputs used in processing production, *IA_exports* and *IA_imports* are the share of IA exports and imports in the firm's total processing exports and imports, respectively. Since firm productivity may influence firm's input and output, TFP (OP) is also included as an additional control variable in these specifications. When exploring the ratio of imported inputs, we alternatively employ the full sample of hybrid exporters and processing exporters, the sample excluding excessive importers, and the sample excluding excessive importers and exporters. We further drop outliers whose ratio of imported input is greater than 1. When exploring the share of IA, the full sample is employed. Since the records of CCTS in 2007 do not distinguish between materials imports and equipment imports nor distinguish between IA and PA trade regimes, we rely on data for the period 2000 to 2006.

Results are reported in Table 1.8. In columns (1)-(3), we use the full sample of hybrid exporters and processing exporters, the sample excluding excessive importers, and the sample excluding excessive importers and exporters, respectively, and regress the share of imported inputs for processing production on the dummy variable for hybrid exporters together with the usual set of control variables. In columns (4)-(5), we regress the proportions of IA exports and imports in total processing exports and imports on the dummy variable. In columns (1)-(3), the coefficients of the dummy variable are significant and negative, indicating that hybrid exporters employ less imported inputs in processing production than processing exporters.[19] Columns (4)-(5) show that hybrid exporters and processing exporters have no significant differences in their participation in IA and PA trade regimes. Despite that IA exports hold a rising position in China's total processing exports, the switch from PA trade regime to IA trade regime seems not to be a motive for the better performance of hybrid exporters.

[19] Table A8 reports the results using the share of processing exports in the firm's total sales as the basis for inputs allocation, and further verifies the robustness of the results in Table 1.8.

Table 1.8: Share of imported inputs and participation in IA

| | (1) $m^F$ ratio | (2) $m^F$ ratio | (3) $m^F$ ratio | (4) IA_exports | (5) IA_imports |
|---|---|---|---|---|---|
| Hybrid | -0.064*** | -0.063*** | -0.067*** | 0.003 | -0.004 |
| | (0.008) | (0.009) | (0.008) | (0.013) | (0.012) |
| TFP(OP) | -0.015*** | -0.013*** | -0.015*** | 0.005** | 0.005** |
| | (0.004) | (0.005) | (0.005) | (0.002) | (0.002) |
| Foreign share | 0.114*** | 0.103*** | 0.101*** | 0.017 | 0.015* |
| | (0.007) | (0.007) | (0.007) | (0.011) | (0.009) |
| ln Age | 0.002 | 0.001 | -0.004 | 0.004 | 0.003 |
| | (0.004) | (0.004) | (0.004) | (0.004) | (0.004) |
| ln Asset | 0.010** | 0.003 | -0.000 | 0.063*** | 0.061*** |
| | (0.005) | (0.005) | (0.004) | (0.010) | (0.010) |
| ln Labor | 0.007* | 0.009** | 0.008* | -0.031*** | -0.030*** |
| | (0.004) | (0.004) | (0.004) | (0.007) | (0.008) |
| ln Subsidy | -0.002* | -0.003 | -0.001 | 0.003 | 0.002 |
| | (0.001) | (0.002) | (0.002) | (0.002) | (0.002) |
| Liquidity | 0.010 | 0.007 | 0.010 | 0.029*** | 0.029*** |
| | (0.006) | (0.007) | (0.007) | (0.007) | (0.007) |
| Interest rate | -0.097 | -0.098 | -0.088 | 0.012 | 0.007 |
| | (0.085) | (0.083) | (0.080) | (0.035) | (0.030) |
| Year-Industry-Province FE | Y | Y | Y | Y | |
| Observations | 35069 | 28591 | 23912 | 40793 | 40793 |
| $R^2$ | 0.259 | 0.271 | 0.275 | 0.441 | 0.446 |

*Notes*: Dependent variables in columns (1)-(3) are the share of imported inputs in total inputs used in processing production, in columns (4)-(5) are the share of IA exports and imports in firm's total processing exports and imports. In columns (1)-(3) we respectively use the full sample of hybrid exporters and processing exporters, the sample excluding excessive importers, and the sample excluding excessive exporters and importers. In columns (4)-(5) we use the full sample. We use date for the period 2000-2006 for regressions of this table. Contrast group is processing exporters. All regressions include year-4-digit industry-province fixed effect. Standard errors clustered at the 4-digit industry level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

### 1.6.2 Product quality, R&D activities, and imported equipment

Product quality may also be affected by firm's R&D activities and by the introduction of new production equipment. Firms investing more in innovation, such as product innovation and process innovation, tend to report higher product quality (López-Mielgo et al., 2009). Therefore, we examine whether R&D activities and imported equipment for processing production can explain the difference in performance between hybrid exporters and processing exporters. We use the value of R&D expenditure (*lnR&D*) and R&D intensity (*RD_intensity*) to measure firm's R&D activities. The R&D intensity is the percentage of R&D expenditure in revenue. As ASIF only discloses the R&D expenditures of firms for the time period 2005-2007, we restrict our sample to this period. Similarly, we use the value of the imported processing equipment (*lnEquipment*) and its intensity (*Equipment_intensity*) to measure the application of imported equipment in production. The imported equipment intensity is calculated as the percentage of the value of imported equipment in capital stock. We use data for the period 2000 to 2006 when investigating imported equipment. We employ these four indicators in specification (1.1) as our dependent variables.

Table 1.9 reports our results. In columns (1)-(2), we respectively regress the logarithm of R&D expenditure and R&D intensity on the dummy variable for hybrid exporters; in columns (3)-(4), we regress the logarithm of value of imported processing equipment and imported equipment intensity on the dummy variable. Estimates show that compared to processing exporters, hybrid exporters carry out more R&D activities and employ more imported equipment in processing production. These two aspects most likely contribute to the higher quality of products exported by hybrid exporters.

Table 1.9: R&D activities and imported equipment for processing production

| | (1)<br>ln R&D | (2)<br>RD_intensity | (3)<br>ln Equipment | (4)<br>Equipment_intensity |
|---|---|---|---|---|
| Hybrid | 0.352*** | 0.109*** | 0.073*** | 0.002** |
| | (0.072) | (0.040) | (0.024) | (0.001) |
| Foreign share | -0.359*** | -0.037 | -0.005 | 0.000 |
| | (0.081) | (0.039) | (0.023) | (0.001) |
| ln Age | 0.104*** | 0.027 | 0.025* | 0.001* |
| | (0.027) | (0.020) | (0.013) | (0.001) |
| ln Asset | 0.284*** | 0.032*** | 0.036*** | 0.001*** |
| | (0.037) | (0.010) | (0.008) | (0.000) |
| ln Labor | 0.092*** | -0.017 | 0.036*** | 0.001** |
| | (0.021) | (0.012) | (0.012) | (0.001) |
| ln Subsidy | 0.105*** | 0.014 | -0.008* | -0.000** |
| | (0.016) | (0.015) | (0.004) | (0.000) |
| Liquidity | 0.092** | 0.042* | -0.050*** | -0.002** |
| | (0.036) | (0.023) | (0.018) | (0.001) |
| Interest rate | 2.691** | 0.354 | -0.032 | -0.001 |
| | (1.053) | (0.450) | (0.062) | (0.002) |
| Year-Industry-Province FE | Y | Y | Y | Y |
| Observations | 26315 | 26315 | 42296 | 42296 |
| $R^2$ | 0.303 | 0.408 | 0.158 | 0.148 |

*Notes*: Dependent variables in columns (1)-(4) are the following: log R&D expenditure, the percentage of R&D expenditure in revenue, log value of imported processing equipment, and the percentage of imported equipment in capital stock. In columns (1)-(2), we employ the data in 2005-2007; in columns (3)-(4), we use the data in 2000-2006. Contrast group is processing exporters. All regressions include year-4-digit industry-province fixed effect. Standard errors clustered at the 4-digit industry level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

### 1.6.3 Alternative explanations: export license and location

In this section, we discuss two other factors that may cause differences in the performance of exporters engaged in processing trade. The first is the abolition of the export license system. China implemented the export license system before 2004, during this period only firms that obtained the export license were eligible to engage in trade. This system was abolished in 2004, granting to all active firms in China the export rights except for a small number of product categories (Branstetter and Lardy, 2006). The number of exporting firms increased dramatically afterwards (Khandelwal et al., 2013). It may be the case that under the export license system, hybrid and processing exporters were subject to different regulations on the content of trade that they could engage in, which can lead to differences in performance. To examine this conjecture, we explore whether the differences in performance between hybrid exporters and processing exporters change before and after the reform of the export license system. Panel A of Table 1.10 reports estimates for the pre-reform period, while Panel B reports estimates for the post-reform period, suggesting that the export license system does not determine differences in performance between hybrid and processing exporters.

In section 1.3.3, we briefly described differences in the location of hybrid exporters and processing exporters across the Chinese territory. More than 70 percent of processing exporters are concentrated in Guangdong Province, while hybrid exporters are more evenly distributed across the different provinces. An intuitive inference would be that Guangdong Province has attracted too many firms by its excellent geographical location, which, on the contrary, may raise the prices of local production materials and general production costs. If the aggregation of firms in Guangdong Province generates negative effects, it should also affect hybrid exporters based in this province. To verify whether the location of firms can explain differences in performance, we construct the dummy variable *Guangdong* that equals 1 when the firm is located in Guangdong Province. We add this dummy variable to specification (1.1) to replace the previous dummy variable *Hybrid* and employ only data from hybrid exporters in these regressions. Panel C of Table 1.10 reports estimates and shows that the performance of hybrid exporters in Guangdong Province is worse than that of hybrid exporters in other Chinese provinces. This result is supportive of the conjecture that the firm's location plays a role in its performance. Notably, the majority of firms located in this area are purely processing exporters. Diseconomies due to firm agglomeration and cost increases are then additional channels to consider when discussing the dissimilar performance of firms engaged in processing trade (Lin et al., 2011; Beaudry and Swann, 2009; Folta et al., 2006).

Table 1.10: Alternative explanations

| | (1) ln VA | (2) ln Profit | (3) ln Revenue | (4) TFP(OP) | (5) TFP(ACF) | (6) ln LabPro |
|---|---|---|---|---|---|---|
| *Panel A: Pre-reform of Export License System* | | | | | | |
| Hybrid | 0.136*** | 0.204*** | 0.082*** | 0.152*** | 0.063** | 0.175*** |
| | (0.030) | (0.051) | (0.029) | (0.033) | (0.028) | (0.030) |
| Control Variables | Y | Y | Y | Y | Y | Y |
| Year-Industry-Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 18597 | 18597 | 18597 | 18597 | 18597 | 18597 |
| $R^2$ | 0.698 | 0.517 | 0.778 | 0.622 | 0.842 | 0.397 |
| | (1) ln VA | (2) ln Profit | (3) ln Revenue | (4) TFP(OP) | (5) TFP(ACF) | (6) ln LabPro |
| *Panel B: Post-reform of Export License System* | | | | | | |
| Hybrid | 0.133*** | 0.225*** | 0.110*** | 0.120*** | 0.081*** | 0.171*** |
| | (0.030) | (0.052) | (0.029) | (0.029) | (0.028) | (0.038) |
| Control Variables | Y | Y | Y | Y | Y | Y |
| Year-Industry-Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 18446 | 18446 | 18446 | 18446 | 18446 | 18446 |
| $R^2$ | 0.709 | 0.522 | 0.756 | 0.613 | 0.835 | 0.420 |
| | (1) ln VA | (2) ln Profit | (3) ln Revenue | (4) TFP(OP) | (5) TFP(ACF) | (6) ln LabPro |
| *Panel C: Sample of Hybrid Exporters* | | | | | | |
| Guangdong | -0.276*** | -0.725*** | -0.209*** | -0.225*** | -0.011 | -0.405*** |
| | (0.043) | (0.089) | (0.031) | (0.040) | (0.015) | (0.047) |
| Control Variables | Y | Y | Y | Y | Y | Y |
| Year-Industry-Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 27261 | 27261 | 27261 | 27261 | 27261 | 27261 |
| $R^2$ | 0.682 | 0.490 | 0.751 | 0.593 | 0.809 | 0.322 |

*Notes*: Dependent variables in columns (1)-(6) are the follows: log value added, log profit, log revenue, TFP(Olley-Pakes), TFP(ACF), and log labor productivity. Panel A reports results of pre-reform period, and panel B reports results of post-reform period. Panel C uses the sample of only hybrid exporters. All regressions control for firm size, age, ownership structure, financial constraints, and subsidies, and include year-4-digit industry-province fixed effect. Standard errors clustered at the 4-digit industry level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

## 1.7 Concluding remarks

A relevant share of trade flows involving emerging economies is nowadays still due to processing trade. While this is a privileged avenue for emerging economies to integrate into Global Value Chains (GVCs) with developed economies, the effects on the domestic economy given the performance of firms involved in this specific trade regime has been questioned in the literature. This paper employs firm level balance sheet data and customs trade data, to provide new stylized facts on the performance of Chinese exporting firms. We investigate differences in performance distinguishing firms with respect to the share of processing trade. In particular, we assess whether the performance of processing firms which also report ordinary trade flows (hybrid) differs from the performance of exporters exclusively involved in processing trade. We find that, among others, hybrid exporters report higher value added, higher labor productivity, and higher total factor productivity, compared to purely processing firms. Our estimates also show that hybrid firms report higher export revenues than processing firms when shipping the same products to the same destination markets.

We find that these differences in firm performance are driven by the possibility of hybrid firms to access to domestic inputs. The increased productivity of domestic input suppliers is indeed positively affecting the performance of hybrid firms.

Previous studies showed that input tariff exemptions and the income tax benefits granted to processing exporters provide low innovation incentives to these firms and therefore explain their worse performance with respect to ordinary exporters. Our results suggest that, among processing trade exporters, those which are able to access domestic inputs can report a better performance. Hybrid firms also export processed goods of higher quality and tend to be more specialized as they supply a lower number of different products to the different destination markets than purely processing firms. Our findings show that sizable differences are present among exporting firms operating under different trade regimes, and that the significant reduction in the share of processing trade over Chinese total trade in recent years might be substantiated by the economic channels described in the present study.

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## 1.8 Appendix

## TFP estimation

Our data preparation for TFP estimation is based on Brandt et al. (2012) and Dai et al. (2016). We use the perpetual inventory method and the real depreciation rate in ASIF to calculate the capital stock. Output and input are deflated as follows. In order to accurately capture the price trends of firms, we employ the method of Smeets and Warzynski (2013) to construct firm-level price index by means of the firm-product level trade information disclosed in CCTS and then deflate the output of exporters. The input deflation index is constructed using the industry output deflation index and the Chinese Input-Output Table for the year 2002. We employ the Brandt-Rawski index to deflate investments.

We then employ the semi-parametric estimation methods proposed by Olley and Pakes (1996) and Ackerberg et al. (2015) for the TFP estimate. We rely on a logarithmic Cobb-Douglas production function:

$$Y_{it} = \beta_0 + \beta_L L_{it} + \beta_K K_{it} + w_{it} + \epsilon_{it}, \tag{A1}$$

where $Y_{it}$, $L_{it}$, $K_{it}$, and $w_{it}$ are respectively the log value added, log labor, log capital, and productivity of firm $i$ in year $t$.

**Olley-Pakes approach**. Suppose that the firm's expectation for future productivity depends on its contemporaneous productivity ($w_{it}$), and firm's investment is modeled as $inv_{it} = I(w_{it}, K_{it})$ that is increasing in capital and productivity. Then, the productivity of firm $i$ can be expressed as the inverted function of investment:

$$w_{it} = I^{-1}(K_{it}, inv_{it}). \tag{A2}$$

Hence the specification to be estimated is:

$$Y_{it} = \beta_L L_{it} + g(K_{it}, inv_{it}) + \epsilon_{it}, \tag{A3}$$

and $g(K_{it}, inv_{it}) = \beta_0 + \beta_K K_{it} + I^{-1}(K_{it}, inv_{it})$. We follow Olley and Pakes (1996) and use fourth-order polynomials as the approximation for $g(.)$:

$$g(K_{it}, inv_{it}) = \sum_{r=0}^{4-s} \sum_{s=0}^{4} \beta_{rs} K_{it}^{r} inv_{it}^{s}. \tag{A4}$$

In the first step, we estimate equation (A3) to obtain estimates for $\hat{\beta}_L$ as well as $\hat{Y}_{it}$. Then $\hat{g}(K_{it}, inv_{it})$ is derived as $\hat{Y}_{it} - \hat{\beta}_L L_{it}$.

The second step is to estimate the coefficient of $K_{it}$, $\hat{\beta}_K$. To do so, we assume that the firm's productivity evolves according to a first-order Markov process, $w_{i,t+1} = f(w_{it}) + \zeta_{i,t+1}$, and $f(w_{it})$ is strictly increasing in $K$ and $inv$. Notice that:

$$f(w_{it}) = f(I^{-1}(K_{it}, inv_{it})) = f(g_{it} - \beta_K K_{it}). \tag{A5}$$

Introducing $\hat{g}_t$ obtained in the first step into (A5) provides the estimation specification for step 2:

$$Y_{i,t+1} - \hat{\beta}_L L_{i,t+1} = \beta_K K_{i,t+1} + f(g_{it} - \beta_K K_{it}) + \zeta_{i,t+1} + \epsilon_{i,t+1}. \tag{A6}$$

We use fourth-order polynomials in $\hat{g}_{it}$ and $K_{it}$ to approximate $f(g_{it} - \beta_K K_{it})$, and use non-linear least squares for estimation. The estimated $TFP(OP)$ is then:

$$TFP(OP)_{it} = Y_{it} - \hat{\beta}_L L_{it} - \hat{\beta}_K K_{it}. \tag{A7}$$

Considering the possible differences in the production functions between industries, we estimate TFP by 2-digit CIC industry.

**ACF approach.** Ackerberg et al. (2015) make assumptions on timing as follows. $K_{it}$ is chosen at $t-1$, intermediate input is determined at $t$, and $L_{it}$ is chosen at $t-b$, $0 < b < 1$ due to labor market frictions (e.g, training time for employees). We use intermediate inputs as the proxy for unobserved productivity. Firm's demand for intermediate input at $t$ depending on $L_{it}$ is equal to:

$$M_{it} = m_t(w_{it}, K_{it}, L_{it}). \tag{A8}$$

Then $w_{it}$ derives from the inverted function of $M_{it}$ and the first stage specification yields as:

$$Y_{it} = \beta_K K_{it} + \beta_L L_{it} + m_t^{-1}(M_{it}, K_{it}, L_{it}) + \epsilon_{it}. \tag{A9}$$

We use third-order polynomials $\Phi(M_{it}, K_{it}, L_{it})$ to approximate $\beta_K K_{it} + \beta_L L_{it} + m_t^{-1}$, hence in the first step, $\Phi(M_{it}, K_{it}, L_{it})$ is estimated as the output net of $\epsilon_{it}$.

Assume that productivity evolves as a first order Markov process, $w_{it} = f(w_{i,t-1}) + \zeta_{it}$, hence $E(\zeta_{it}|K_{it}) = 0$ and $E(\zeta_{it}|L_{i,t-1}) = 0$ according to the timing assumptions. Starting with an initial guess for the parameters $\beta_K$ and $\beta_L$ with OLS regression, we obtain a preliminary estimate of $w_{it}$ and $w_{i,t-1}$ by the following specifications:

$$w_{it}(\beta_K, \beta_L) = \hat{\Phi}(M_{it}, K_{it}, L_{it}) - \beta_K K_{it} - \beta_L L_{it}, \quad \text{(A10)}$$

$$w_{i,t-1}(\beta_K, \beta_L) = \hat{\Phi}(M_{i,t-1}, K_{i,t-1}, L_{i,t-1}) - \beta_K K_{i,t-1} - \beta_L L_{i,t-1}. \quad \text{(A11)}$$

In the second step, we regress $w_{it}(\beta_K, \beta_L)$ on $w_{i,t-1}(\beta_K, \beta_L)$ to obtain the residuals $\hat{\zeta}_{it}(\beta_K, \beta_L)$, followed by the last step where we obtain the parameters $\hat{\beta}_K$ and $\hat{\beta}_L$ which set the following moment conditions to zero:

$$\frac{1}{T}\frac{1}{N}\sum_t \sum_i \hat{\zeta}_{it}(\beta_K, \beta_L) \begin{pmatrix} K_{it} \\ L_{i,t-1} \end{pmatrix} \quad \text{(A12)}$$

The estimated $TFP(ACF)$ is finally computed with $\hat{\beta}_K$ and $\hat{\beta}_L$. The production function is estimated for each 2-digit CIC industry as well.

## Chinese industries under analysis

We investigate the following Chinese manufacturing industries with a 2-digit CIC code between 13 and 42: agricultural and sideline food processing (13); food manufacturing (14); beverage manufacturing (15); tobacco products manufacturing (16); textiles (17); apparel, shoes, and hat manufacturing (18); leather, fur, feather (velvet) and their products (19); wood processing and wood, bamboo, rattan, palm, and grass products (20); furniture manufacturing (21); paper and paper products (22); printing and recording media reproduction (23); cultural, educational, and sporting products manufacturing (24); petroleum processing, coking and nuclear fuel processing (25); chemical raw materials and chemical products manufacturing (26); pharmaceutical manufacturing (27); chemical fiber manufacturing (28); rubber products (29); plastic products (30); non-metallic mineral products (31); ferrous metal smelting and rolling processing (32); non-ferrous metal smelting and rolling processing (33); metal products (34); general equipment manufacturing (35); special equipment manufacturing (36); transportation equipment manufacturing (37); electrical machinery and equipment manufacturing (39); communication equipment, computer, and other electronic equipment manufacturing (40); instrumentation, cultural, and office machinery manufacturing (41); handicrafts and other manufacturing (42).

Figure A1: DVAR of processing exports in 2000-2007, based on single-industry exporters

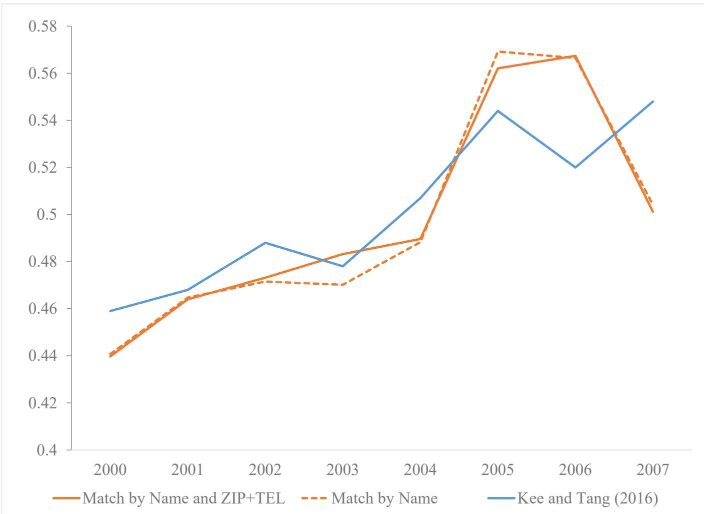


Table A1: Share of number of firms and of export value, by processing status

| | In this paper | | In Dai et al. (2016) | |
|---|---|---|---|---|
| | # of firms | Export value | # of firms | Export value |
| Processing exporters | 18.06% | 31.26% | 15.30% | 21.30% |
| Hybrid exporters | 27.96% | 55.45% | 32.20% | 63.70% |
| Non-processing exporters | 53.97% | 13.29% | 52.40% | 15.00% |

*Notes*: Processing exporters are firms reporting only processing exports each recorded year; hybrid exporters are firms reporting both processing exports and ordinary exports each recorded year; non-processing exporters are firms reporting only ordinary exports each recorded year.

Table A2: Robustness check for firm-level performance of hybrid and processing exporters, separate fixed effects

| | (1) ln VA | (2) ln Profit | (3) ln Revenue | (4) TFP(OP) | (5) TFP(ACF) | (6) ln LabPro |
|---|---|---|---|---|---|---|
| Hybrid | 0.121*** | 0.226*** | 0.084*** | 0.132*** | 0.069*** | 0.154*** |
| | (0.018) | (0.034) | (0.021) | (0.019) | (0.020) | (0.024) |
| Foreign share | -0.006 | 0.140*** | -0.014 | -0.089*** | -0.055*** | 0.001 |
| | (0.023) | (0.041) | (0.019) | (0.022) | (0.016) | (0.029) |
| ln Age | 0.027*** | -0.187*** | 0.029*** | -0.005 | -0.048*** | -0.069*** |
| | (0.009) | (0.027) | (0.010) | (0.011) | (0.013) | (0.016) |
| ln Asset | 0.624*** | 0.851*** | 0.660*** | 0.321*** | 0.349*** | 0.248*** |
| | (0.020) | (0.024) | (0.019) | (0.014) | (0.016) | (0.012) |
| ln Labor | 0.345*** | 0.207*** | 0.291*** | -0.108*** | -0.416*** | |
| | (0.015) | (0.021) | (0.012) | (0.012) | (0.036) | |
| ln Subsidy | 0.000 | 0.032*** | 0.005 | 0.005 | 0.006** | -0.014*** |
| | (0.004) | (0.006) | (0.003) | (0.004) | (0.003) | (0.004) |
| Liquidity | 0.257*** | 1.065*** | 0.176*** | 0.412*** | 0.121*** | 0.412*** |
| | (0.027) | (0.070) | (0.024) | (0.033) | (0.023) | (0.035) |
| Interest rate | 0.138 | -1.353*** | 0.178 | 0.078 | 0.228 | 0.161 |
| | (0.183) | (0.307) | (0.258) | (0.131) | (0.214) | (0.131) |
| Year FEs | Y | Y | Y | Y | Y | Y |
| Province FEs | Y | Y | Y | Y | Y | Y |
| Industry FEs | Y | Y | Y | Y | Y | Y |
| Observations | 42322 | 42322 | 42322 | 42322 | 42322 | 42322 |
| $R^2$ | 0.651 | 0.446 | 0.723 | 0.560 | 0.803 | 0.309 |

*Notes*: This table reports results of specification (1.1) with separate fixed effects. Dependent variables in columns (1)-(6) are the follows: log value added, log profit, log revenue, TFP(Olley-Pakes), TFP(ACF), and log labor productivity. Contrast group is processing exporters. All regressions include year, 4-digit industry, and province fixed effects. Standard errors clustered at the 4-digit industry level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A3: Firm-level performance of hybrid, processing, and non-processing exporters

| | (1) ln VA | (2) ln Profit | (3) ln Revenue | (4) TFP(OP) | (5) TFP(ACF) | (6) ln LabPro |
|---|---|---|---|---|---|---|
| Hybrid | 0.168*** | 0.337*** | 0.112*** | 0.163*** | 0.101*** | 0.225*** |
| | (0.019) | (0.037) | (0.021) | (0.019) | (0.022) | (0.027) |
| Non-processing | 0.197*** | 0.377*** | 0.132*** | 0.234*** | 0.124*** | 0.392*** |
| | (0.026) | (0.044) | (0.026) | (0.024) | (0.029) | (0.029) |
| Foreign share | 0.015 | 0.208*** | 0.004 | -0.030* | -0.039*** | 0.084*** |
| | (0.016) | (0.025) | (0.015) | (0.017) | (0.012) | (0.026) |
| ln Age | 0.039*** | -0.132*** | 0.036*** | 0.010 | -0.033*** | -0.032** |
| | (0.009) | (0.018) | (0.009) | (0.010) | (0.009) | (0.013) |
| ln Asset | 0.579*** | 0.821*** | 0.603*** | 0.278*** | 0.298*** | 0.224*** |
| | (0.014) | (0.017) | (0.012) | (0.012) | (0.024) | (0.011) |
| ln Labor | 0.359*** | 0.214*** | 0.305*** | -0.098*** | -0.384*** | |
| | (0.011) | (0.015) | (0.010) | (0.011) | (0.046) | |
| ln Subsidy | 0.005** | 0.028*** | 0.008*** | 0.011*** | 0.009*** | -0.008*** |
| | (0.002) | (0.004) | (0.002) | (0.002) | (0.002) | (0.002) |
| Liquidity | 0.295*** | 1.118*** | 0.205*** | 0.505*** | 0.181*** | 0.395*** |
| | (0.020) | (0.050) | (0.019) | (0.024) | (0.028) | (0.025) |
| Interest rate | 0.613 | -0.454 | 0.589 | 0.513 | 0.500 | 0.451* |
| | (0.450) | (0.445) | (0.489) | (0.386) | (0.337) | (0.255) |
| Year*Industry*Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 78678 | 78678 | 78678 | 78678 | 78678 | 78678 |
| $R^2$ | 0.687 | 0.498 | 0.736 | 0.599 | 0.829 | 0.395 |

*Notes*: Dependent variables in columns (1)-(6) are the follows: log value added, log profit, log revenue, TFP(Olley-Pakes), TFP(ACF), and log labor productivity. Contrast group is processing exporters. All regressions include year-4-digit industry-province fixed effect. Standard errors clustered at the 4-digit industry level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A4: A preliminary check on the degree of vertical integration of hybrid and processing exporters

| | (1)<br>Value added to sales | (2)<br>Value added to sales |
|---|---|---|
| Hybrid | 0.001 | -0.011 |
| | (0.008) | (0.015) |
| Foreign share | | -0.011 |
| | | (0.018) |
| ln Age | | 0.035 |
| | | (0.032) |
| ln Asset | | 0.042 |
| | | (0.053) |
| ln Labor | | 0.017*** |
| | | (0.005) |
| ln Subsidy | | -0.009 |
| | | (0.008) |
| Liquidity | | -0.077 |
| | | (0.112) |
| Interest rate | | 0.234 |
| | | (0.305) |
| Year-Industry-Province FE | Y | Y |
| Observations | 53784 | 53784 |
| $R^2$ | 0.499 | 0.500 |

*Notes*: This table reports results of the comparison of the degree of vertical integration between hybrid and processing exporters. Dependent variables are the ratio of value added to sales. Contrast group is processing exporters. All regressions include year-4-digit industry-province fixed effect. Standard errors clustered at the 4-digit industry level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A5: Robustness check for the comparison in DVAR (2000-2006)

| | (1) DVAR | (2) DVAR |
|---|---|---|
| Hybrid | 0.022** | 0.024*** |
| | (0.009) | (0.007) |
| Foreign share | -0.022*** | -0.006 |
| | (0.008) | (0.008) |
| ln Age | 0.004* | 0.010*** |
| | (0.003) | (0.003) |
| ln Asset | -0.014** | -0.010** |
| | (0.005) | (0.005) |
| ln Labor | 0.015*** | 0.018*** |
| | (0.004) | (0.003) |
| ln Subsidy | 0.003** | 0.001 |
| | (0.001) | (0.001) |
| Liquidity | 0.005 | 0.006 |
| | (0.005) | (0.004) |
| Interest rate | -0.001 | -0.000 |
| | (0.008) | (0.008) |
| Year-Industry-Province FE | Y | Y |
| Observations | 31161 | 26241 |
| $R^2$ | 0.268 | 0.266 |

*Notes*: This table reports results of specification (1.9) with data for 2000-2006. Dependent variables in columns (1)-(2) are the DVAR of processing exports. In column (1), excessive importers are excluded, and in column (2), both excessive importers and excessive exporters are excluded. Contrast group is processing exporters. All regressions include year-4-digit industry-province fixed effect. Standard errors clustered at the 4-digit industry level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A6: Robustness check for the role of DVAR in firm performance (2000-2006)

| | (1) ln VA | (2) ln Profit | (3) ln Revenue | (4) TFP(OP) | (5) TFP(ACF) | (6) ln LabPro |
|---|---|---|---|---|---|---|
| *Panel A: Sample of Hybrid Exporters* | | | | | | |
| DVAR | 0.085* | 0.234** | -0.002 | 0.060 | -0.034 | 0.100** |
| | (0.050) | (0.094) | (0.041) | (0.054) | (0.029) | (0.049) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | Y | Y | Y | Y | Y |
| Observations | 13109 | 13109 | 13109 | 13109 | 13109 | 13109 |
| $R^2$ | 0.883 | 0.793 | 0.942 | 0.826 | 0.925 | 0.776 |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| | ln VA | ln Profit | ln Revenue | TFP(OP) | TFP(ACF) | ln LabPro |
| *Panel B: Sample of Processing Exporters* | | | | | | |
| DVAR | -0.115 | 0.130 | -0.115 | -0.137 | -0.050 | -0.153 |
| | (0.111) | (0.162) | (0.085) | (0.115) | (0.052) | (0.118) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | Y | Y | Y | Y | Y |
| Observations | 5307 | 5307 | 5307 | 5307 | 5307 | 5307 |
| $R^2$ | 0.859 | 0.765 | 0.943 | 0.796 | 0.918 | 0.755 |

*Notes*: This table reports results of specification (1.10) with data for 2000-2006. Dependent variables in columns (1)-(6) are the follows: log value added, log profit, log revenue, TFP(Olley-Pakes), TFP(ACF), and log labor productivity. Both excessive importers and excessive exporters are excluded. All regressions control for firm size, age, ownership structure, financial constraints, and subsidies, and include year and firm fixed effects. Standard errors clustered at the 4-digit industry level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A7: Robustness check for the driving forces of differentiated DVAR (2000-2006)

| | (1) $\Delta$DVAR | (2) $\Delta$Relative price | (3) $\Delta$Domestic upstream varieties | (4) $\Delta$Upstream market concentration | (5) $\Delta$Upstream input tariff | (6) $\Delta$FDI |
|---|---|---|---|---|---|---|
| $\Delta$Relative price | 0.206*** | | | | | |
| | (0.021) | | | | | |
| $\Delta$Upstream input tariff | | -0.400*** | 0.008 | 0.379*** | | |
| | | (0.020) | (0.019) | (0.036) | | |
| $\Delta$Domestic upstream varieties | | 0.090*** | | | | |
| | | (0.020) | | | | |
| $\Delta$Upstream market concentration | | -0.039*** | | | | |
| | | (0.008) | | | | |
| $\Delta$Exchange rates | | -1.052*** | 0.036 | 0.642*** | | |
| | | (0.031) | (0.026) | (0.142) | | |
| $\Delta$FDI | | | 0.050*** | -0.018 | | |
| | | | (0.012) | (0.018) | | |
| Hybrid | | 0.001 | 0.001 | 0.003 | -0.019*** | 0.032*** |
| | | (0.001) | (0.001) | (0.005) | (0.005) | (0.008) |
| Year-Industry-Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 29983 | 29983 | 29983 | 29983 | 29983 | 29983 |
| $R^2$ | 0.078 | 0.845 | 0.201 | 0.428 | 0.237 | 0.303 |

*Notes*: This table reports results of specifications (1.11)-(1.16) with data for 2000-2006. Studied variables are the change of the variable of interest in each year relative to the value in the first year that this firm enters the sample. Dependent variables in columns (1)-(6) are the change of: DVAR, log relative price, log domestic upstream varieties, log upstream market concentration, log upstream input tariffs, and log own-industry FDI. Both excessive importers and excessive exporters are excluded. All regressions include the year-2-digit industry-province fixed effect. Standard errors clustered at the 4-digit industry level are reported in parentheses. $^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$.

Table A8: Robustness check for the share of imported inputs in processing production

| | (1) $m^F$ ratio | (2) $m^F$ ratio | (3) $m^F$ ratio |
|---|---|---|---|
| Hybrid | -0.047*** | -0.056*** | -0.059*** |
| | (0.008) | (0.008) | (0.007) |
| TFP(OP) | 0.007*** | 0.014*** | 0.018*** |
| | (0.003) | (0.002) | (0.002) |
| Foreign share | 0.069*** | 0.045*** | 0.025*** |
| | (0.007) | (0.008) | (0.007) |
| ln Age | 0.005 | -0.001 | -0.008** |
| | (0.003) | (0.003) | (0.003) |
| ln Asset | 0.006 | 0.009 | 0.004 |
| | (0.006) | (0.006) | (0.005) |
| ln Labor | 0.009* | -0.003 | -0.007 |
| | (0.005) | (0.006) | (0.005) |
| ln Subsidy | -0.005*** | -0.005*** | -0.003** |
| | (0.001) | (0.001) | (0.001) |
| Liquidity | 0.002 | 0.001 | 0.004 |
| | (0.007) | (0.007) | (0.005) |
| Interest rate | -0.020 | -0.018 | -0.013 |
| | (0.029) | (0.021) | (0.021) |
| Year-Industry-Province FE | Y | Y | Y |
| Observations | 29905 | 26594 | 21975 |
| $R^2$ | 0.307 | 0.304 | 0.312 |

*Notes*: Dependent variables in columns (1)-(3) are the share of imported inputs in total inputs used in processing production, using the share of processing exports in the firm's total sales (recorded in ASIF) as the basis for the firm to allocate intermediate inputs. In columns (1)-(3), we respectively use the full sample of hybrid exporters and processing exporters, the sample excluding excessive importers, and the sample excluding excessive exporters and importers, for the period 2000-2006. Contrast group is processing exporters. All regressions include year-4-digit industry-province fixed effect. Standard errors clustered at the 4-digit industry level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

# 2

# China's losing late-developing advantage: An analysis of processing trade and growth

*Joint work with Changying Li and Chunkai Wang*

## 2.1 Introduction

China has been implementing the national strategy of opening up the domestic market and introducing foreign direct investment (FDI) since 1978, with the aim of enhancing technological capability and facilitating the integration of domestic firms into the global economy. For one thing, the introduction of competition can force domestic firms to improve production and management efficiency. Secondly, domestic firms can be encouraged to learn foreign advanced knowledge by outsourcing business, the production for original equipment manufacturers, or cooperative production, so as to strengthen independent innovation and competitiveness. China's processing trade thereby thrived with favorable policies and continuous FDI inflows, accounting for the majority of China's total exports in the first decade of the 2000s, and is believed to be one of the leading causes for the Chinese trade boom of that time.

After absorbing considerable imported materials and equipment as well as foreign knowledge through processing trade, China has achieved a rising position in global value chains (GVCs). However, preventing spillovers is becoming more fundamental for foreign firms as Chinese firms steadily progress in the international market.[1] Therefore, our concern is, can Chinese firms continue to benefit from spillovers from the processing trade?

To answer this question, we first consider an outsourcing model comprising spillovers and dissect the competition and cooperation between Chinese and foreign firms. Results show that facing the augmented absorptive capacity of Chinese firms for spillovers and their rising competitiveness, foreign firms eventually turn to deterring competition rather than seeking cooperation and attempt to prevent spillovers by reducing the technological content of outsourcing production. In other words, in the metamorphosis from "Made in China" to "Designed in China," Chinese firms are bound to experience a bottleneck period when foreign firms in developed economies cut back knowledge diffusion. The rapid rise of Chinese firms will accelerate to offset their learning opportunities in the outsourcing business and will quickly squeeze China's late-developing advantage.

We then employ the production data of Chinese manufacturing firms and the customs data on firm transactions, both for the period 2000 to 2007, to examine the dynamic trends in intra-firm and inter-firm spillovers from processing trade. Intra-firm spillovers refer to the effects on processing firms, and inter-firm spillovers

[1] An instance is the 2014 FAW Mazda technology transfer agreement rumor. More details can be found at http://www.nbd.com.cn/articles/2014-01-16/803701.html.

refer to the influences of processing firms on domestic non-processing firms in the same industry (horizontal spillovers) and in the upstream industries (backward spillovers). In assessing the firm's outcomes, we consider firm productivity and the export performance of private-label (ordinary) products, including the product varieties, product quality, the number of overseas markets, and export revenue.

We use the fixed effects model and propensity score matching combined with the difference-in-difference approach (PSM-DID) to examine intra-firm spillovers. We find significant and positive spillovers on the productivity and the product varieties of entrants into the processing trade. Productivity spillovers are, however, only significant in the short run, and product variety-promoting spillovers eventually remain at a stable level in the long run, suggesting there is an upper limit of learning space in processing production. In examining inter-firm spillovers, we employ the time differencing and fixed effects model that controls for market competition. We find negative backward productivity spillovers on domestic non-exporting firms and positive horizontal productivity spillovers on domestic ordinary exporters in the base year (2002). Both sorts of spillovers decrease in scale in subsequent years.

We focus on the interactions between the innovation activities of domestic non-processing firms and inter-firm spillovers as the factor explaining the evolving paths of spillovers. We find different motives for the trends in inter-firm spillovers stemming from different sources. Processing firms bring production and product information to the other non-processing firms and generate diverse input demands, motivating domestic upstream non-exporting firms to focus on product development rather than productivity enhancement. This interference with productivity is gradually relieved by the technological advancement of domestic non-exporting firms. We do not find evidence of the innovation activities of domestic ordinary exporters discouraging them from benefiting from horizontal productivity spillovers, implying that the lessening trend of this sort of spillovers is associated with external causes such as the shrinking positive externalities of processing firms led by controls over spillovers.

The flourish of China's processing trade results in an increasing focus on its strategic significance to economic and industrial development. Processing trade is argued to assume the growth engine for Chinese coastal regions (Fu, 2004), as foreign-invested processing firms bring information spillovers about international markets and promote the export performance of local firms (Fu, 2011). The value added in China's industrial exports also correlates to the processing trade, as Xu and Lu (2009) argue that a larger share of processing exports accounted for by foreign-invested firms contributes to the higher value added in China's exports. Kee and Tang (2016) point out that the substitution of domestic inputs for imported materials by processing exporters is the premier driver of the remarkable increase in the domestic content embodied in China's exports in the period 2000–2007.

Different opinions on the contributions of processing trade are present as well. Fu (2011) suggests the depressing effects of foreign-invested processing firms on the export propensity of local firms. Ouyang and Fu (2012) propose that FDI flowing into processing production in southern China does not generate positive spillovers in the inland regions, as processing trade demands few domestic inputs and yields insufficient inter-industry linkages to inland regions. Dai et al. (2016) point out the lower productivity of purely processing firms than firms engaged in ordinary exports. They attribute the result to the self-selection of firms with less technology capacity into processing trade. Manova et al. (2015) also argue that firms reporting more financial constraints tend to enter the export market with processing trade.

The above studies are revelatory, however, they do not consider the dynamic adjustment of the impact of processing trade. We contribute to this field by identifying the dynamic trends of spillovers from the processing trade. We highlight that processing trade provides limited learning space to Chinese firms, and their rapid growth has triggered the responses of foreign firms to spillovers.

Studies on the spillovers from the FDI are another related line to this paper, given the prominent role of the FDI in the development of China's processing trade (Fu, 2011). The extant literature has put forward prolific evidence of positive spillovers from the FDI, for instance, the productivity spillovers and export-promoting spillovers on the acquired plants in Indonesia (Arnold and Javorcik, 2009), and spillovers on the local suppliers of foreign-invested firms (Blalock and Gertler, 2008).[2] Concerning the FDI in China, Kee and Tang (2016) present evidence supportive of the FDI stimulating the varieties of domestic inputs. Lu et al. (2017) propose the competitive effects of the FDI in China. Our study provides stylized facts for spillovers from the FDI-dominant processing trade in China and points out the decreasing trend of horizontal productivity spillovers, potentially providing an explanation for the result of Lu et al. (2017) in light of the large proportion of processing production inside foreign-invested firms in China.[3]

In the rest of the paper, section 2.2 introduces the processing trade in China.

[2] An additional sample of literature on FDI spillovers is Javorcik (2004), Guadalupe et al. (2012), Girma and Görg (2007), Chen (2011), Javorcik and Spatareanu (2008), Görg and Strobl (2005), and Kugler (2006).

[3] Processing exports accounted for more than 70 percent of the total exports of foreign-invested firms between 2000–2011, as illustrated in Figure 2.2(a) in this paper.

Section 2.3 presents an outsourcing model, taking into account technology spillovers, and explains how the learning ability of Chinese firms affects the technological content of outsourcing production. Section 2.4 describes the data and measurements of firm performance and spillovers. Section 2.5 investigates the trends in spillovers from processing trade, followed by section 2.6 examining the possible explanations. Section 2.7 concludes.

## 2.2 Outline of China's processing trade

Processing trade stems from the early stages of China's reform and opening up in the 1970s, developed to solve the contradiction between China's severe shortage of capital and technology and the urgent need to integrate into the global economy. Benefiting from the economic globalization and accession to the WTO, China drew tremendous FDI into processing production that mainly includes pure assembly (PA) production and import and assembly (IA) production.[4] Processing trade gradually became the primary means for Chinese firms to participate in GVCs prior to the year 2011. Figure 2.1(a) reports China's export composition for the period 2000–2011, indicating that processing exports contributed a considerable share to China's gross exports. The continuous inflows of FDI also established the dominant share of foreign-invested firms in China's processing trade firms in this period.[5] As shown in Figure 2.1(b), foreign-invested firms accounted for, on average, more than 80 percent of China's annual processing exports.

With the exception of low-cost labor, FDI prefers processing production in China due to the following incentives. One is the low investment costs. In China, foreign investment is not necessarily in the form of currency but can be in the form of imported capital goods, such as machinery and equipment, industrial property rights, and proprietary technology. Therefore, foreign-invested firms often offset the legal requirement on investment with imported capital goods. Secondly, China implements preferential policies for processing trade. The imported raw materials used for the processing production are exempt from import tariffs conditional on the processed finished products being re-exported, which are exempt from the

[4] The difference between IA and PA regimes lies in the ownership of imported inputs and equipment for processing production. Under the PA regime, foreign firms own production materials and equipment, and processing firms only earn processing fees. Under the IA regime, processing firms pay for imported materials and re-export processed products to foreign markets.

[5] According to the related regulations in China, a firm is classified as foreign-invested if foreign capital accounts for no less than 25 percent of its paid-in capital.

Figure 2.1: China's export composition, 2000–2011


(a) Gross exports, by trade regime (b) Processing exports, by ownership type

*Source: China Customs Statistical Yearbook* and CCTS.

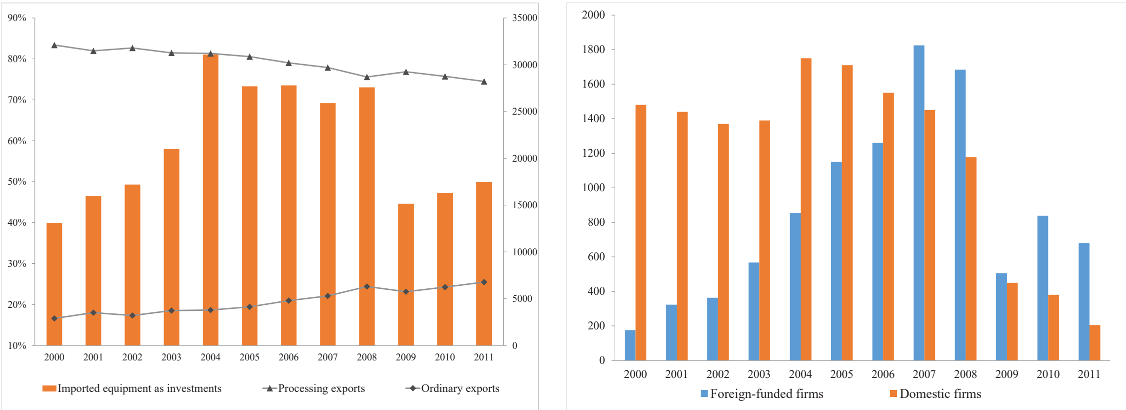
export tariffs.[6] During the investigated period (2000–2007), two more favorable policies were in place. Foreign-invested firms located in special economic zones or engaged in production and located in economic and technological development zones, and foreign firms setting up production in special economic zones, were granted a reduced rate of corporate income tax of 15 percent. The other policy offered a reduction of the corporate income tax to export-oriented firms, provided that the firm's annual exports accounted for more than 70 percent of its total output (Dai et al., 2016). Most firms engaged in processing trade meet the export threshold and are thereby entitled to the tax incentives.

These policies save a great number of costs and simplify the trade procedures of foreign investors to participate in processing production in China, leading to uneven magnitudes of the ordinary exports and processing exports of foreign-invested firms. Figure 2.2(a) summarizes the export composition of foreign-invested firms as well as their imported capital goods for the purpose of investment during the period 2000–2011. One can infer that most imported properties were devoted to processing production by the fact that processing trade accounted for more than 70 percent of exports.

Domestic processing firms have less access to foreign equipment, by contrast. Figure 2.2(b) reports the annual imports of equipment specified for pure assembly (PA) production in the year 2000 to 2011. Domestic processing firms, on average, are provided approximately US$ 1,500 million worth of foreign equipment annu-

[6] Regulations Governing Customs Control on the Importation and Exportation of Goods for Inward Processing, 1988.

Figure 2.2: Imported capital goods for processing production (million US$), 2000–2011




(a) Foreign-invested firms' export composition and capital imports

(b) Equipment imports specified for PA, by ownership type

ally before the financial crisis of 2008, which is far less than the imported capital goods applied in processing production by foreign-invested firms, as described in Figure 2.2(a). The opportunity provided by the favorable policies attracted foreign investors to open factories in China, which explains the distinct levels of imported equipment and export volumes between processing firms of different ownership types. The incentive of foreign firms to control spillovers may also be an alternative and deeper cause. Rather than pursuing Chinese partners, the direct investment enabled them to more closely manage production materials and production processes thereby reducing possible spillovers.

## 2.3 A conceptual framework

To depict the competition and cooperation in the area of outsourcing business between Chinese and foreign firms, based on Dixit and Stiglitz (1977) and Melitz (2003), we consider a model where the firm in the developed country outsources production to Chinese firms and determines the technological content endogenously. We aim to analyze how China's open policy and Chinese firms' understanding of spillovers affect the technology embodied in outsourcing production.

The model includes a developed country and China. In the international market (two countries) of a particular category of products, a total of n+2 firms each produce a substitute. Firm $A$ is in the developed country, and firm $B$ as well as n symmetric other firms $(N_1, \ldots, N_n)$ are in China. Only these n+2 substitutes are assumed to circulate on the international market for the sake of simplification. The amount of labor in the developed country and China is respectively $L_A$ and $L_B$. China has a comparative advantage in labor costs, with the unit labor cost in the developed country equal to one and China's equal to $w < 1$. $A$ can decide whether to outsource production tasks to China, while only firm $B$ can take up the work. Other n Chinese firms are not engaged in outsourcing production. The consumer base of the two countries is composed of their workforce. The budget constraint of each consumer is the wage income, and the utility function of the representative consumer is:

$$U = \left[ \left(q^A\right)^{\frac{\sigma-1}{\sigma}} + \left(q^B\right)^{\frac{\sigma-1}{\sigma}} + \sum_{j=1}^{n} \left(q^{N_j}\right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \tag{2.1}$$

where $q^A$ and $q^B$ are the consumption of the products of firms $A$ and $B$, respectively, and $q^{N_j}, j = 1, \ldots, n$ is the consumption of the products of the $j$th other firms. $\sigma > 1$ is substitution elasticity and remains constant. Assuming that the labor and product markets both happen to clear, the total consumption in the international market can be expressed as $R = wL_B + L_A$.

These n+2 firms engage in monopolistic competition. Denote the marginal cost of firms $A$, $B$, and other firms as $c^A$, $c^B$, and $c^{N_j}, j = 1, \ldots, n$. The product price of each firm is:

$$p^i = \frac{\sigma}{(\sigma - 1)} c^i, i = A, B, N_1, \ldots, N_n. \tag{2.2}$$

According to Dixit and Stiglitz (1977), the market output and price indexes are given by

$$Q = \left[ \left(q^A\right)^{\frac{\sigma-1}{\sigma}} + \left(q^B\right)^{\frac{\sigma-1}{\sigma}} + \sum_{j=1}^{n} \left(q^{N_j}\right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \tag{2.3}$$

$$P = \left[ \left(p^A\right)^{1-\sigma} + \left(p^B\right)^{1-\sigma} + \sum_{j=1}^{n} \left(p^{N_j}\right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}. \tag{2.4}$$

The output of each firm is:

$$q^i = Q \left( \frac{P}{p^i} \right)^{\sigma}, i = A, B, N_1, \ldots, N_n. \tag{2.5}$$

The market share of each firm is $M^i = \frac{p^i q^i}{\sum p^i q^i}, i = A, B, N_1, \ldots, N_n$, which can be further simplified as

$$M^i = \left(\frac{p^i}{P}\right)^{1-\sigma}, i = A, B, N_1, \ldots, N_n. \tag{2.6}$$

Therefore, the sales revenue of each firm is $r^i = M^i R, i = A, B, N_1, \ldots, N_n$. Assuming zero sales cost besides production costs, the profit function of each firm is

$$\pi^i = \frac{r^i}{\sigma} - f^i, i = A, B, N_1, \ldots, N_n, \tag{2.7}$$

where $f^i$ is the fixed costs. From equation (2.7) we know that the firm's profit correlates to its market share, thus profit maximization for a firm is equivalent to the maximization of market share due to the constant substitution elasticity.

Modern products have more complex structural components or require multiple production processes (Grossman and Rossi-Hansberg, 2008). Therefore, a product can be regarded as the collection of multiple products (production tasks). Given this, we assume that the production processes of these n+2 products can be denoted by a continuous set $\Phi = [0, 1]$, with $\phi \in \Phi$ representing one of the production tasks. If $\phi$ is closer to 1, the process of this task has higher technological content and is thus more labor demanding. Conversely, $\phi$ closer to 0 represents less technological content, and the task is simpler and less labor demanding.

Since the products of firms $A$, $B$, and n other firms are substitutes, we assume that these firms have the same production process. For example, they could all be mobile phone manufacturers and use the same assembly line to produce mobile phones of different brands. Assuming that all Chinese firms $(B, N_1, \ldots, N_n)$ have the same technology capacity, while firm $A$ is more technologically advanced and more productive. The distinction of productivity is manifested by the assumption that for tasks of the same technological level, firm $A$ requires less labor input. Moreover, firm $A$'s comparative advantage to Chinese firms enlarges in the technological content of tasks, and the gap in demanded labor widens. The labor input for task $\phi \in [0, 1]$ of each firm is:

$$L(\phi) = \begin{cases} e^{\phi}, & for\ firm\ A \\ e^{\lambda\phi}, & for\ firms\ B\ and\ N_1, \ldots, N_n. \end{cases} \tag{2.8}$$

Standardize the technological level of firm $A$ to 1, $\lambda < 1$ is the relative technological level of firms $B$ and $N_1, \ldots, N_n$. Assuming zero fixed costs, the unit production cost is the labor cost which equals

$$c^i = \begin{cases} \int_0^1 e^{\phi} d\phi, & for\ firm\ A \\ w \int_0^1 e^{\lambda\phi} d\phi, & for\ firms\ B\ and\ N_1, \ldots, N_n, \end{cases} \tag{2.9}$$

$i = A, B, N_1, \ldots, N_n$. The marginal cost functions are then given by $c^A = (e-1)$, $c^B = c^{N_j} = \frac{w}{\lambda}(e^{\lambda} - 1), j = 1, \ldots, n$.

### 2.3.1 Outsourcing decision of the foreign contractor

The intention of foreign contractors such as firm $A$ is to take advantage of the cheaper labor in developing countries, so the present model only considers the scenario of firm $A$ outsourcing production tasks to firm $B$. Therefore, firm $A$ decides whether to outsource production tasks and how many to outsource. Generally speaking, firms tend to outsource low-value-added or low-tech tasks and keep high-value-added or high-tech tasks for themselves. We assume firm $A$ will outsource tasks that have a technological level no higher than $\phi^* \in [0, 1]$ to firm $B$, and take up tasks with a technological level larger than $\phi^*$. On account of the assumption, when firms engage in outsourcing production, the marginal cost function of each firm can be rewritten as

$$c^{io} = \begin{cases} w\tau \int_0^{\phi^*} e^{\phi} d\phi + \int_{\phi^*}^1 e^{\phi} d\phi, & for\ firm\ A \\ w\left(\int_0^{\phi^*} e^{\delta\phi} d\phi + \int_{\phi^*}^1 e^{\lambda\phi} d\phi\right), & for\ firm\ B \\ w\left(\int_0^{\phi^*} e^{\delta'\phi} d\phi + \int_{\phi^*}^1 e^{\lambda\phi} d\phi\right), & for\ firms\ N_1, \ldots, N_n, \end{cases} \tag{2.10}$$

$i = A, B, N_1, \ldots, N_n$ and the superscript $io$ denotes the case of outsourcing. For firm $A$, $\tau \geq 1$ is the iceberg cost of outsourcing and $w\tau \leq 1$ assures $A$'s benefits from outsourcing. Denote by $\chi$ the learning and absorptive capacity of firm $B$ for the technological content of outsourcing tasks. $\delta = \lambda - \chi(\lambda - 1)$ that maps to $\chi$ is the new relative technological level of $B$ among tasks that are before $\phi^*$. Given $\delta$ is increasing in $\chi$, $\chi = 0$ suggests that firm $B$ learns nothing from outsourcing tasks. On the contrary, $\chi = \delta = 1$ suggests that firm $B$ absorbs the entire technological content of outsourcing tasks and improves its technology at the production stage $[0, \phi^*]$ to the same level as firm $A$. The technology spillovers from outsourcing business may break through firm boundaries via channels such as employee turnovers, leading to knowledge diffusion from firm $B$ to other firms in China. Assume that $\chi' \in [0, 1]$ represents the absorptive capacity of other Chinese firms for spillovers, and these firms can raise their technological level relative to firm $A$ to $\delta'$ at production stage $[0,\phi^*]$. $\delta' \in [1,\lambda]$ likewise increases in $\chi'$. The basic logic of equation (2.10) is the strategic relation between firm $A$ and Chinese firms. Firm $A$ lowers its marginal cost to $w\tau$ in the production stage $[0,\phi^*]$ at the cost of potential technology spillovers to Chinese firms.

Combining equations (2.4) and (2.6), the market share of each firm in the case of outsourcing is

$$M^{AO}(\phi) = \left(\frac{p^{AO}(\phi)}{P^O}\right)^{1-\sigma} = \left[\frac{\sigma}{\sigma-1}\frac{w\tau\left(e^{\phi}-1\right)+\left(e-e^{\phi}\right)}{P^O}\right]^{1-\sigma}, \tag{2.11}$$

$$M^{BO}(\phi) = \left(\frac{p^{BO}(\phi)}{P^O}\right)^{1-\sigma} = \left[\frac{\sigma}{\sigma-1}\frac{w}{P^O}\left(\frac{e^{\delta\phi}-1}{\delta}+\frac{e^{\lambda}-e^{\lambda\phi}}{\lambda}\right)\right]^{1-\sigma}, \tag{2.12}$$

$$M^{NO_j}(\phi) = \left(\frac{p^{NO_j}(\phi)}{P^O}\right)^{1-\sigma} = \left[\frac{\sigma}{\sigma-1}\frac{w}{P^O}\left(\frac{e^{\delta'\phi}-1}{\delta}+\frac{e^{\lambda}-e^{\lambda\phi}}{\lambda}\right)\right]^{1-\sigma}, \tag{2.13}$$

$j = 1,\ldots,n$. $p^{AO}(\phi)$, $p^{BO}(\phi)$, and $p^{NO_j}(\phi)$ are the product price of firms $A$, $B$, and the $j$th other firms in the case of outsourcing, respectively.

$P^O = \left[\left(p^{AO}\right)^{1-\sigma}+\left(p^{BO}\right)^{1-\sigma}+\sum_{j=1}^{n}\left(p^{NO_j}\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$ is the market price index in the case. Notice that the prices of firm $B$ and other Chinese firms are in the function of the market share of firm $A$, outsourcing thereby inevitably leads to opposite changes in firm $A$'s market share and profit. One is the cost-saving effect of the cheaper labor employed in outsourcing production, which enlarges $A$'s market share. The other is the competitive effect, as Chinese firms can utilize the technology spillovers from outsourcing production and narrow their technology gaps with respect to $A$ at the production stage $[0,\phi^*]$. The resulted cost savings enable Chinese firms to offer lower prices and seize a partial market share of firm $A$. The profit maximization of firm $A$ is hence to choose an optimal outsourcing threshold $\phi^*$ to maximize its market share, namely,

$$\max_{\phi\epsilon[0,1]} M^{AO}(\phi). \tag{2.14}$$

Take the logarithm of (2.14) and solve $\phi^*$ with the first-order condition (F.O.C),

$$FOC: \left.\frac{\partial ln(M^{AO}(\phi))}{\partial\phi}\right|_{\phi=\phi^*} = 0. \tag{2.15}$$

Expanding the F.O.C gives us

$$\left.\frac{\partial ln(M^{AO}(\phi))}{\partial\phi}\right|_{\phi=\phi^*} = (1-\sigma)\left[\frac{\partial ln(p^{AO}(\phi))}{\partial\phi} - \frac{\partial ln(P^{O}(\phi))}{\partial\phi}\right]_{\phi=\phi^*} = 0. \quad (2.16)$$

The first term of the right-hand side of equation (2.16) embodies $A$'s cost descending rate due to outsourcing, and the second term reflects the descending rate of the market price index under the compound effects of outsourcing. Thus, firm $A$ must carefully weigh cost savings against the fiercer competition.

Corollary 2.1 yields here.

**Corollary 2.1.** *One of the following three scenarios necessarily holds:*

*(1) If* $\left[\frac{\partial ln(p^{AO}(\phi))}{\partial\phi} > \frac{\partial ln(P^{O}(\phi))}{\partial\phi}\right]_{\phi=1}$*, given* $w\tau$ *and* $\sigma$ *are relatively large while* $\delta$ *and* $\delta'$ *are low, there is a unique internal solution to the optimization problem of firm A.*

*(2) If* $\left[\frac{\partial ln(p^{AO}(\phi))}{\partial\phi} > \frac{\partial ln(P^{O}(\phi))}{\partial\phi}\right]_{\phi=1}$*, given* $w\tau$ *and* $\sigma$ *are significantly low while* $\delta$ *and* $\delta'$ *are close to* $\lambda$*, the optimization problem of firm A has only corner solutions.*

*(3) If* $\left[\frac{\partial ln(p^{AO}(\phi))}{\partial\phi} \leq \frac{\partial ln(P^{O}(\phi))}{\partial\phi}\right]_{\phi=1}$*, then the optimization problem of firm A has only a corner solution.*

*Proof.* See the Appendix. □

The first bullet of corollary 2.1 indicates a situation in which, given the inequality at $\phi = 1$, if outsourcing brings modest cost savings to firm $A$ yet Chinese firms learn fast and have the absorptive capacity for spillovers, and the n+2 products are strong substitutes, firm $A$ will only outsource partial production to China. The second and third bullets indicate the situations where firm $A$ will not outsource at all or will outsource all tasks. On account of the gap in labor costs between China and foreign developed countries and the speed of the technological advances of Chinese firms, we believe the first situation is realistic, and we will focus on that case in the following analysis.

### 2.3.2 Impact of opening preferential policies

China has implemented multiple preferential policies for promoting FDI in the past decades. Corollary 2.2 summarizes how these policies affect the technological content of outsourcing business.

**Corollary 2.2.** $\left.\frac{\partial \phi^*}{\partial \tau}\right|_{\phi=\phi^*} < 0$, *indicating that the smaller the iceberg cost* ($\tau$), *the higher the threshold of the technological content of outsourcing* ($\phi^*$). *Foreign firms are willing to outsource the production tasks with higher technological levels to China as the cost of outsourcing decreases.*

*Proof.* See the Appendix. □

Corollary 2.2 shows that a higher degree of China's openness leads to lower costs of outsourcing for foreign firms, which is more conducive to attracting outsourcing with more technological content. This conclusion certifies the rationality of the strategy of trading the domestic market for technology and promoting development through reform at the beginning of China's reform and opening up.

### 2.3.3 Impact of the absorptive capacities of Chinese firms

China's preferential policies for foreign firms create precious opportunities for domestic firms to learn advanced production and foreign products. However, foreign firms will inevitably take measures against technology leakage. It is proved that $\frac{\partial \phi^*}{\partial \delta} > 0$ and $\frac{\partial \phi^*}{\partial \delta'} > 0$, with $\delta$ and $\chi$ ($\delta'$ and $\chi'$) reversely changing, hence $\phi^*$ decreases as $\chi$ and $\chi'$ increase. This results in corollary 2.3.

**Corollary 2.3.** *With Chinese firms' enhancing absorptive capacities for spillovers and their resulting technological progress, foreign firms will gradually reduce the technological content of outsourcing.*

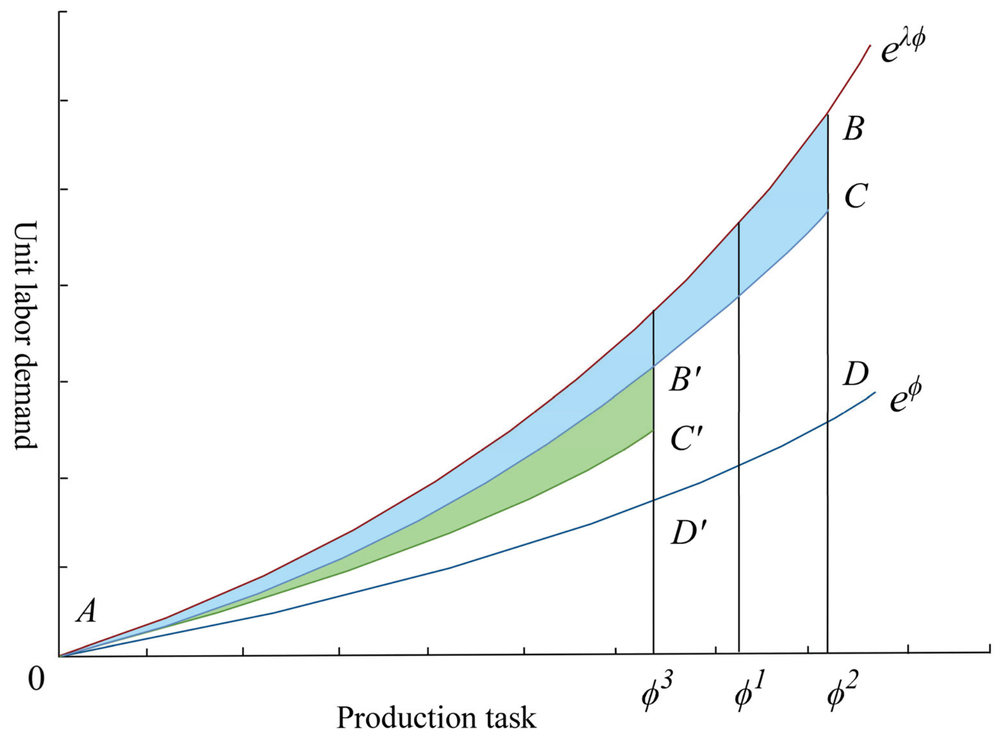
*Proof.* See the Appendix. □

It can be seen that the policy of attracting outsourcing through preferential policies therefrom generating learning opportunities is periodic and unsustainable in the long term. Even in some extreme cases of zero iceberg cost, it can be proved that if Chinese firms are substantially enabled in learning foreign technology, foreign firms will not outsource high-tech businesses to China.

### 2.3.4 Implications

The above analysis shows that Chinese firms' appropriation of technology spillovers will continuously reduce the willingness of firms in developed countries to outsource high-tech production tasks, and the strategies of learning from outsourcing motivated by preferential policies will thereby be ultimately invalidated. Figure 2.3 depicts the learning potential of Chinese firms for technology in the face of a representative foreign contractor. The initial technology threshold of the foreign contractor for outsourcing business is $\phi_1$, which increases to $\phi_2$ upon the implementation of preferential policies. The production technology curve of Chinese firms shifts from $AB$ to $AC$ depending on the current absorptive capacity for spillovers, resulting in a cost-saving with the size of $ABC$. Then, the cost-saving potential from technology spillovers for Chinese firms becomes $ACD$. The learning behaviors of Chinese firms, however, reduce the technological content of outsourcing business, in turn, moving the threshold to $\phi_3$ and the production technology curve of Chinese firms to $AC'$. Although the productivity of Chinese firms is further enlarged by the size of the area $AB'C'$, the potential for future cost reductions by technology spillovers is suppressed to the size of the area $AC'D'$.

Figure 2.3: Chinese firms' learning space for technology through processing trade




The results shed light on our empirical investigation. Considering that outsourcing business in China is mostly in the form of processing trade, combined with data availability, we propose the following hypotheses on spillovers from China's processing trade for the empirical study.

*Hypothesis 1.* Processing trade generates intra-firm spillovers. Processing firms can gain technological know-how and export-related knowledge from the processing production. Nevertheless, the progress of processing firms will prompt foreign firms to place an upper limit on the knowledge of outsourcing production to control further spillovers.

Given that processing firms have more access to imported materials and equipment and accumulate relative knowledge of international trade, they may yield spillovers on other Chinese firms that do not engage in processing trade. We thus propose hypothesis 2.

*Hypothesis 2*. Processing firms bring multi-dimensional information about foreign products, production processes, and international markets to domestic non-processing firms and promote the latter's productivity or export performance. The growth of domestic non-processing firms, however, exposes the competitive pressures on foreign firms and will trigger foreign firms' controls over spillovers from the processing trade.

## 2.4 Data and measurement

We employ two sets of data to investigate spillovers from the processing trade. The first database is the *Annual Survey of Industrial Firms panel* (ASIF) for the period 2000 to 2007, maintained by China's National Bureau of Statistics (NBS), covering all state-owned and non-state-owned firms with annual sales of at least 5 million RMB, spanning from mining and logging, manufacturing to utility industries. ASIF provides the balance sheet, income statement, and cash flow statement as well as firm-specific information such as name, address, belonging industry, year and month of establishment, and ownership structure of each firm.[7] The second available database is the *Chinese Customs Trade Statistics* (CCTS) recording China's import and export transactions for the period 2000 to 2007. CCTS provides the importing countries or exporting destinations, transaction value in US dollars, quantity, and the trade regime of every transacted product at the HS 8-digit level, sourced from the General Administration of Customs of China.

We firstly use the firm name to match the same firm in the two databases. For firms that fail to be matched by name, we use the last seven digits of the phone number and the postal code as an alternative identifier for matching. We

[7] Following Dai et al. (2016), we wash the database by dropping: (1) records where the main variables are negative or missing, including industrial sales, revenue, export value, total fixed assets, net fixed assets, and intermediate inputs; (2) records with fewer than 8 employees; (3) records with the export value exceeding the total industrial sales, or total assets fewer than total fixed assets or current assets, or accumulated depreciation fewer than the current year's depreciation; (4) records with an unreasonable month or year of establishment.

exclude characters that would interfere with matching from the identifiers.[8] Since we focus on the spillovers from processing trade, we retain firms from manufacturing industries as they contribute the vast majority of China's processing exports.[9] We successfully merge around 53 percent of manufacturing exporters in ASIF, including 273,828 observations from 88,212 firms.[10] The merged data represents about 40 percent of China's total exports and 52 percent of processing exports in the investigated period, suggesting a good representation of China's trade flows. To fully capture industry structures, our sample for analysis comprises all merged exporters, non-exporting firms, and unmerged exporters recorded in ASIF: a total of 1,495,931 observations from 470,984 firms.

We attempt to provide evidence of foreign firms' potential responses to spillovers from processing trade by investigating the evolving trends of spillovers. Therefore, it is fundamental to meticulously distinguish between processing firms that generate spillovers and domestic learning firms that appropriate spillovers. To this end, relevant firms are classified into two categories according to the trade regime that they participate in: (1) processing firms that report processing transactions in any given year; (2) domestic non-processing firms that do not report processing transactions in any given year, including non-exporting firms that report only domestic sales in any given year, and ordinary exporters that report only non-processing (ordinary) exports in any given year.[11] Exporters recorded in ASIF that fail to merge with CCTS are excluded from the group of learning firms, as it is unclear which trade regimes these firms are involved in. Their information is employed only in the measurements of industry competition and spillovers.

### 2.4.1 Measuring firm performance

A large number of imported materials and even equipment are used in processing production, and the processed finished products need to conform to foreign specifications and quality standards. Processing firms can thereby accumulate knowledge about international markets alongside possible productivity gains. When process-

[8] The following characters are identified and excluded: full-width and half-width brackets, single and double quotes, hyphens, underline, dot, square brackets, slash, asterisk, and inequality signs.

[9] These firms' two-digit China's GB/T industry classification (CIC) codes are between 13 and 42. The mapping between industry codes and names is reported in the Appendix.

[10] We are able to merge more exporters with the refined identifiers compared to the literature. For instance, Dai et al. (2016) merge about 45 percent of exporters in ASIF for the period 2000 to 2006.

[11] 112 exporters that do not report processing transactions or ordinary exports, but transactions under other trade regimes (e.g., compensating trade), are classified into the category of ordinary exporters. They only account for roughly 0.16 percent of the group of domestic ordinary exporters.

ing firms also produce private-label (ordinary) products, those accumulated experiences shall be applied to the production of ordinary products. For example, the imported intermediate inputs of more varieties or higher quality of processing production may motivate firms to apply similar inputs to ordinary production, thereby improving the competitiveness of the private brands. Processing firms can also learn about prevalent products in foreign markets and develop similar private-label products through imitation and expand the product scope. The production for firms based in different foreign countries may enhance the overseas marketing channels. We therefore consider the firm's production efficiency and the performance of ordinary exports.

We use the total factor productivity ($TFP_{it}$) to capture the firm's production technology, estimated by following the semi-parametric estimation method proposed by Ackerberg et al. (2015). Since we focus on the difference between firms within the industry, we employ the method of Smeets and Warzynski (2013) and construct the firm-level price index for exporters using the firm-product-level trade information disclosed in CCTS. Given there is no available information on the product prices of non-exporting firms, for those firms we use the industry-level output deflator. Considering the possible differences in the production functions between industries, we estimate the TFP by the 3-digit CIC industry.[12] On evaluating the performance of ordinary exports, we use the number of different HS6 products exported under the ordinary trade regime to represent the varieties of the firm's private-label products ($Variety_{it}$), and count the exporting destinations of the firm's ordinary exports as the number of overseas markets ($Market_{it}$). The revenue of ordinary exports measures the foreign demands of the firm's private products ($OrdExp_{it}$).[13] Also, by drawing on the method of Khandelwal et al. (2013), the product quality of every firm-year-HS6 product-export destination pair is estimated from a CES function which incorporates the horizontal and vertical differentiation of products, based on the transaction data recorded in CCTS and the data of the country-sector-level elasticity of substitution provided by Broda et al. (2006). To eliminate the influence of outliers, we truncate the quality estimates at the 1st and 99th percentiles. Firm-level quality ($Quality_{it}$) is obtained as the average quality weighted by the share of a single firm-year-HS6 product-export

[12] The Appendix provides the procedure followed in the estimation of TFP.
[13] The revenue of ordinary exports is also deflated by the firm-level price index.

destination pair in the firm's total ordinary exports.[14]

### 2.4.2 Measuring spillovers

We consider intra-firm and inter-firm spillovers from processing trade in China. On the intra-firm spillovers. If the efficiency progress of processing firms, which results from the learning-by-doing effects and demonstrates the capability to undertake more complex production tasks, helps them obtain processing production tasks of increasing technological complexity, implying no significant control over spillovers. In this case, the technology enhancement of processing firms has a positive interaction with the technological content of processing production, thus, firm performance is supposed to exhibit a continuously rising trend in a longer engagement in processing trade. In contrast, the performance of processing firms does not continue to rise in the further participation in processing trade, suggesting the upper limit of learning space from processing production. We therefore examine the relationship between the number of years the firm has been reporting processing transactions ($Length_{it}$) and its performance.

Inter-firm spillovers include horizontal spillovers occurring within the industry, and forward and backward spillovers taking place in supply chains via backward-forward linkages (Javorcik, 2004; Görg and Strobl, 2005; Damijan et al., 2013). Forward spillovers refer to the benefits of downstream firms from sourcing inputs of superior quality or additional varieties from upstream firms of higher technological levels; backward spillovers may happen to upstream firms if they supply technologically advanced downstream firms (Barrios and Strobl, 2002).

In the literature, horizontal spillovers are usually captured by the proportion of sales or employees within each industry accounted for by a category of firms (Caves, 1974; Javorcik, 2004; Zhang et al., 2010). However, since the processed finished products cannot be sold domestically, spillovers from processing exporters caused by product circulation will be trivial. Leininger (2007) suggests that China reports one of the highest employee turnover rates in Asia for the year 2006, we then alternatively consider the knowledge diffusion caused by employees. Therefore, the horizontal spillovers from processing exporters ($Horizontal_{jt}$) are represented by the share of employees accounted for by processing firms in the industry. The as-

[14] It is worth mentioning that the elasticity of substitution for HS3 products is available for 73 countries and regions, therefore, about 26 percent of ordinary exports in our sample are excluded from these estimations. Since the country list covers most of the major trading countries, which are also the main importing countries of China's exports, we believe that the trimming of data exerts moderate effects on our investigation.

sumption for this measurement is that the knowledge brought about by processing production will disseminate among all employees of the firm, including those engaged in and not engaged in processing production. Considering that horizontal spillovers are usually specialized and industry-specific (Fu, 2011), and aggregate studies may not be able to identify the spillovers facing some subsets of firms only (Damijan et al., 2013), we measure the horizontal spillovers of each 4-digit CIC industry.

Also, because of the insignificant domestic circulation of the processed finished products, the forward spillovers from processing firms occurring in vertical supply chains will be minor (Fu, 2011). Kee and Tang (2016) point out that the remarkable increase of domestic value added in China's exports between 2000 to 2007 mainly results from the substitution of domestic for imported inputs in processing production. Domestic upstream suppliers are therefore likely to benefit from the increasing input demands of downstream processing firms and realize production or product improvements. Following Havranek and Irsova (2011), backward spillovers ($Backward_{jt}$) are calculated as the weighted average of horizontal spillovers from processing firms in the 3-digit downstream industries based on the Chinese Input-Output Table for the year 2002.

### 2.4.3 Control variables

In addition to positive externalities, the classic literature on spillovers from FDI points out that the FDI may bring about negative competitive effects on domestic firms operating in the same industry and may lower the latter's productivity (Görg and Strobl, 2005; Javorcik and Spatareanu, 2008; Damijan et al., 2013). This may be because foreign-invested firms seize partial market shares of domestic firms and force them to spread fixed costs over a smaller volume of production (Aitken and Harrison, 1999). Thence, the product-market competition should be taken into account in the investigation of inter-firm spillovers (Haskel et al., 2007). To better isolate spillovers from possible competitive effects, following Javorcik and Spatareanu (2008), Keller and Yeaple (2009), and Haskel et al. (2007), we use three potential measures of market competition: industry concentration ($HHI_{jt}$) proxied by the Herfindahl index, industry markup ($IMarkup_{jt}$) calculated as the average of firm markups weighted by market shares, and firm market share ($MShare_{it}$). Industry concentration and markup are both available at the 4-digit CIC industry level. Firm markup is estimated by following De Loecker and Warzynski (2012), and market share is the proportion of sales accounted for by the firm within the

4-digit CIC industry.

We also employ a vector of firm characteristics, including firm size measured by the number of employees ($Labor_{it}$) and total assets ($Assets_{it}$), plus firm age ($Age_{it}$) which is the number of years the firm has been in operation. The ownership structure is controlled by a dummy variable indicating foreign-invested firms ($FIE_{it}$), and average wage ($AWage_{it}$) is introduced for the proficient level of employees. To control for the firm's capital intensity, $KL_{it}$ is the ratio of log real capital stock to labor. We follow Manova et al. (2015) and consider the firm's financial constraints, $Liquidity_{it}$ is the share of the difference between current assets and liabilities in total assets. Subsidy income received by the firm ($Subsidy_{it}$) is considered as well.

Table 2.1 then reports the statistical description of the variables for different groups of firms discussed in this paper. On average, processing exporters report more than two consecutive years of processing production and higher productivity than domestic non-processing firms.[15] Regarding ordinary products, the product varieties and the number of overseas markets of processing exporters are larger than those of domestic ordinary exporters, which can be explained by product quality to some extent. Compared to domestic ordinary exporters, processing firms also report averagely larger yet more discrete scales of ordinary exports. Among domestic non-processing firms, ordinary exporters appear to benefit more from spillovers than non-exporting firms, while the latter face the least competition pressure as they report the largest average firm markup and second highest average industry markup. Processing exporters are, on average, younger but have a larger size and higher average wage, liquidity, subsidy income, and capital to labor ratio than the other two groups of firms.

[15] TFP measures are demeaned by the average of 4-digit industry-year combinations.

Table 2.1: Descriptive statistics

| | Count | Mean | Median | SD |
|---|---|---|---|---|
| *Panel A: Processing Exporters* | | | | |
| Length | 147,350 | 2.71 | 2.00 | 1.88 |
| TFP | 143,785 | 0.07 | -0.02 | 0.62 |
| Product varieties | 96,232 | 7.35 | 4.00 | 11.72 |
| Number of overseas markets | 96,232 | 7.49 | 4.00 | 9.84 |
| Revenue of ordinary exports | 147,350 | 1,785,904.03 | 85,266.50 | 13,592,558.19 |
| Quality of ordinary exports | 90,781 | -0.43 | 0.45 | 4.61 |
| HHI | 147,350 | 0.02 | 0.01 | 0.03 |
| Market share | 147,350 | 0.00 | 0.00 | 0.02 |
| Markup | 147,249 | 21.99 | 11.23 | 105.52 |
| Industry markup | 147,350 | 49.49 | 35.19 | 85.36 |
| Employee | 147,350 | 514.91 | 231.00 | 1,275.30 |
| Total assets | 147,350 | 161,299.18 | 34,010.50 | 983,294.81 |
| Age | 147,350 | 9.77 | 8.00 | 8.26 |
| Average wage | 147,350 | 19.29 | 14.40 | 72.00 |
| Ratio of capital to labor | 147,350 | 129.68 | 50.67 | 406.22 |
| Liquidity | 147,350 | 0.11 | 0.11 | 0.32 |
| Subsidy | 147,350 | 257.74 | 0.00 | 6,974.29 |
| *Panel B: Domestic Ordinary Exporters* | | | | |
| TFP | 42,925 | 0.03 | -0.02 | 0.66 |
| Product varieties | 43,594 | 3.90 | 2.00 | 5.85 |
| Number of overseas markets | 43,594 | 6.88 | 4.00 | 8.41 |
| Revenue of ordinary exports | 43,632 | 1,491,057.74 | 471,729.50 | 4,194,196.77 |
| Quality of ordinary exports | 38,082 | -0.82 | 0.13 | 4.86 |
| Horizontal spillovers | 43,411 | 0.21 | 0.17 | 0.15 |
| Backward spillovers | 43,632 | 0.13 | 0.11 | 0.10 |
| HHI | 43,632 | 0.02 | 0.01 | 0.03 |
| Market share | 43,632 | 0.00 | 0.00 | 0.01 |
| Markup | 43,606 | 24.35 | 12.77 | 83.86 |
| Industry markup | 43,632 | 43.53 | 34.50 | 62.53 |
| Employee | 43,632 | 303.61 | 137.00 | 636.83 |
| Total assets | 43,632 | 79,109.51 | 19,619.50 | 291,456.04 |
| Age | 43,632 | 11.07 | 7.00 | 12.10 |
| Average wage | 43,632 | 14.87 | 12.00 | 16.93 |
| Ratio of capital to labor | 43,632 | 87.53 | 45.70 | 205.09 |
| Liquidity | 43,632 | 0.04 | 0.04 | 0.31 |
| Subsidy | 43,632 | 216.32 | 0.00 | 2,185.62 |
| *Panel C: Domestic Non-exporting Firms* | | | | |
| TFP | 836,486 | -0.03 | -0.03 | 0.45 |
| Horizontal spillovers | 838,297 | 0.14 | 0.11 | 0.13 |
| Backward spillovers | 852,348 | 0.11 | 0.09 | 0.09 |
| HHI | 852,348 | 0.02 | 0.01 | 0.03 |
| Market share | 852,348 | 0.00 | 0.00 | 0.01 |
| Markup | 850,810 | 28.31 | 12.63 | 139.79 |
| Industry markup | 852,348 | 47.43 | 35.67 | 80.49 |
| Employee | 852,348 | 154.20 | 80.00 | 341.68 |
| Total assets | 852,348 | 32,697.33 | 10,258.00 | 181,509.30 |
| Age | 852,348 | 11.90 | 7.00 | 12.37 |
| Average wage | 852,348 | 12.36 | 9.94 | 29.37 |
| Ratio of capital to labor | 852,348 | 89.66 | 46.49 | 901.77 |
| Liquidity | 852,348 | 0.04 | 0.05 | 0.38 |
| Subsidy | 852,348 | 150.31 | 0.00 | 2,514.16 |

## 2.5 Evolving trends of spillovers from processing trade

### 2.5.1 Intra-firm spillovers

We estimate the following specifications for the first look at spillovers taking place among processing exporters:

$$LnY_{it} = \alpha_0 + \alpha_1 Length_{it} + C'_{ijt}\gamma + u_i + u_t + \varepsilon_{it}, \tag{2.17}$$

and

$$LnY_{it} = \beta_0 + Dummy\_T'_{n,it}\eta + C'_{ijt}\gamma + u_i + u_t + \varepsilon_{it}, \tag{2.18}$$

where $Y_{it}$ is the outcome of firm $i$ in year $t$, including productivity ($TFP_{it}$) and the outcomes of ordinary exports: the product varieties ($Variety_{it}$), product quality ($Quality_{it}$), the number of overseas markets ($Market_{it}$), and export revenue ($OrdExp_{it}$). $Length_{it}$ is the number of years the firm has been consecutively reporting processing transactions in the investigated periods. $Dummy\_T'_{n,it}$, $n = 2, \ldots, 8$ is a vector of dummy variables for the firm's engagement in the processing trade, and $Dummy\_T_{n,it}$ is equal to one if the firm has been reporting processing transactions for $n$ years, and is otherwise zero. The coefficient of $Length$ hence measures the average effect of engaging in processing trade on a specific indicator of firm performance and the coefficients of $Dummy\_T'_{n,it}$ reveal the evolving trend of the effect with respect to the entry year. $C'_{ijt}$ is a series of control variables, including firm characteristics discussed in section 2.4.3 and industry concentration ($HHI_{jt}$). Productivity is controlled when studying the outcomes of ordinary exports. Moreover, as product characteristics such as quality affect the market demands facing a firm (Hallak, 2006), log product quality and log product varieties are further controlled when investigating the number of export destinations and export revenue.[16] We are therefore able to examine whether there are any additional channels of spillovers on export performance other than through improved productivity, product varieties, and quality. $u_i$ is introduced for firm-level unobservables, and $u_t$ is introduced for unknowns in each sample year.

Results are reported in Table 2.2. Columns (1) and (2) signify that participation in processing production in the short run is correlated to slightly higher

[16] As not all processing firms engage in ordinary exports, we use the data of firms that report both ordinary exports and processing transactions simultaneously when examining spillovers on ordinary exports.

productivity compared to the first year that the firm reports processing transactions, while longer participation is instead associated with lower TFP. Columns (3) and (4) convey the modest role of processing production in helping the varieties of ordinary products to flourish. This effect in several post-entry years is reinforced compared to the entry year though not in every year. Columns (5) and (6) show that processing production is uncorrelated to quality improvement. Columns (7)-(10) indicate that after controlling the impacts of productivity, product varieties, and quality, a longer engagement in processing trade is associated with a lower number of foreign markets and less revenue from ordinary exports.

### 2.5.2 A PSM-DID approach

One problem with estimating the causal effects of an entry into processing trade on firm performance with specifications (2.17) and (2.18) is the possible endogeneity of the firm's entry choice. Firms make their decisions on exporting via which trade regime or switching between non-export and export based on their traits at the time. Ideally, we should compare the firm's performance in the post-entry period with the one in the case of not engaging in processing trade, but the counterfactual is naturally inaccessible. Alternatively, we adopt the method of propensity score matching (PSM) combined with the difference-in-difference approach (DID) for further checks on the effects of entry.

Taking into account the possible differences in production and marketing between exporters and non-exporting firms, we group the entrants of processing trade (the treatment group, T) into two sorts: one is firms that do not have export records before entry (group T1), the other is those with experience in ordinary exports before entry (group T2). Accordingly, we employ firms that do not report processing transactions in the whole investigated period as the control group (C) and divide them into two sorts. One is non-exporting firms (group C1), reporting only domestic sales in all recorded years and prepared for the treatment group T1; the other is ordinary exporters (group C2), reporting only ordinary exports in all recorded years and prepared for the treatment group T2. As we aim to examine the trend of intra-firm spillovers from processing trade, we consider the following matching procedure built on Heyman et al. (2007).

We use the Nearest-Neighbor with the replacement method. In the first step, we rescale the time period in such a way that the entry year of a firm is denoted as $s = 1$. Entrants of groups T1 and T2 are respectively assorted into seven subgroups by their length of engagement in processing trade after entry: entrants that report

Table 2.2: Firm performance and the engagement in processing trade

| Dep.Var | (1) Ln TFP | (2) Ln TFP | (3) Ln Variety | (4) Ln Variety | (5) Ln Quality | (6) Ln Quality | (7) Ln Market | (8) Ln Market | (9) Ln OrdExp | (10) Ln OrdExp |
|---|---|---|---|---|---|---|---|---|---|---|
| Length | -0.010*** | | 0.009** | | 0.016 | | -0.010*** | | -0.020** | |
| | (0.003) | | (0.004) | | (0.018) | | (0.003) | | (0.009) | |
| Dummy_T2 | | 0.047*** | | 0.025*** | | -0.017 | | 0.004 | | -0.005 |
| | | (0.005) | | (0.007) | | (0.037) | | (0.006) | | (0.015) |
| Dummy_T3 | | 0.036*** | | 0.033*** | | -0.026 | | -0.008 | | -0.034 |
| | | (0.008) | | (0.010) | | (0.053) | | (0.009) | | (0.023) |
| Dummy_T4 | | 0.009 | | 0.030** | | -0.001 | | -0.021* | | -0.066** |
| | | (0.010) | | (0.014) | | (0.067) | | (0.012) | | (0.030) |
| Dummy_T5 | | -0.009 | | 0.043** | | -0.027 | | -0.025* | | -0.083** |
| | | (0.013) | | (0.017) | | (0.084) | | (0.015) | | (0.039) |
| Dummy_T6 | | -0.030* | | 0.027 | | 0.121 | | -0.040** | | -0.078 |
| | | (0.016) | | (0.021) | | (0.103) | | (0.018) | | (0.048) |
| Dummy_T7 | | -0.063*** | | 0.038 | | 0.151 | | -0.054** | | -0.100* |
| | | (0.019) | | (0.025) | | (0.121) | | (0.022) | | (0.059) |
| Dummy_T8 | | -0.104*** | | 0.096*** | | 0.120 | | -0.087*** | | -0.159** |
| | | (0.023) | | (0.029) | | (0.141) | | (0.026) | | (0.068) |
| Control variables | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Observations | 125741 | 125741 | 79294 | 79294 | 74661 | 74661 | 74661 | 74661 | 74661 | 74661 |
| $R^2$ | 0.938 | 0.938 | 0.805 | 0.805 | 0.686 | 0.686 | 0.882 | 0.882 | 0.825 | 0.825 |

*Notes:* Dependent variables are given in each column heading. TFP is estimated by following Ackerberg et al. (2015). In all regressions, we control for firm age, size, average wage, ownership structure, capital intensity, subsidy, liquidity, and industry concentration. In columns (3)-(10), we further control for productivity; in columns (7)-(10), log product quality and log product varieties are introduced. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at firm level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

processing transactions only in year $s$ (1-year length), or in the years $s$ and $s+1$ (2-year length), increasing by year analogously, until the last group of firms that consecutively report processing transactions in year $s$ to year $s+6$ (7-year length). Firms in control groups C1 and C2 are classified by the same survival criterion. In the second step, we calculate the probability of a firm entering the processing trade using a vector of observable characteristics of firm and industry that explain the firm's choice of entry, which are selected by referring to the literature and conforming to the norm of high R2.[17] One treated firm matches with five nearest untreated firms that are on the common support and survive no less than the length of engagement of the treated firm. The weight of each matched untreated firm is applied in the DID analysis. By this means, we provide every treated firm with comparable untreated firms in each post-entry year. The balancing property of the propensity score is tested and satisfied in all estimations.[18]

As our data is a panel of firms across years, the matching of firms is implemented year-by-year using lagged covariates to control for shocks specific to each year. All matched control firms in previous matching procedures are excluded from the follow-up matching procedures. Moreover, as our interest is the dynamic trends of the treatment effects, we exclude the observations of matched control firms in the post-entry period when the treated firm does not report processing transactions. For example, the treated firm engages in processing production for two more years after entry (i.e., $s+1$, $s+2$), while the matched control firms survive more than two years in the post-entry period. We drop the information of these control firms for years after $s+2$.

We examine the trends of the effects of engaging in processing trade on different indicators of firm performance by estimating the following specifications,

$$LnY_{it} = \alpha_0 + \alpha_1 After_{it} + C'_{ijt}\gamma + u_i + u_j + u_t + \varepsilon_{it}, \tag{2.19}$$

and

$$LnD\_Y_{it} = \beta_0 + \beta_1 Treated_i + C'_{ijt}\gamma + u_j + u_t + u_r + \varepsilon_{it}. \tag{2.20}$$

Specification (2.19) is the classical DID equation, where $After_{it}$ is a dummy

[17] These observables include the firm's total assets, age, employees, labor productivity, average wage, capital intensity, liquidity, industry Herfindahl index, and 4-digit industry classification code. We matched 5,982 untreated firms with 1,733 treated firms of group T1, and 3,894 untreated firms with 1,159 treated firms of group T2.

[18] Partial results of balancing property tests are given in Table B2 and Table B3 in the Appendix.

variable equal to one for the post-entry period.[19] Hence $\alpha_1$ captures the difference in performance between the entrants and non-entrants caused by the entry into the processing trade. Specification (2.20) is adapted from specification (2.19), where $LnD\_Y_{it}$ is the difference in the firm performance at time $t = s$ and at time one year earlier than entry ($s = 0$), namely, $LnD\_Y_{it} = LnY_{i,s} - LnY_{i,0}$. $Treated_i$ is the dummy variable for the entrants to the processing trade, and its coefficient $\beta_1$ describes the evolving path of treatment effects in each post-entry year. The vector of control variables are the same as specifications (2.17) and (2.18). We control for unknowns at firm ($u_i$), industry ($u_j$), and year ($u_t$) levels in specification (2.19), and unobservables at industry, province ($u_r$), and year levels are controlled in specification (2.20). To balance the representativeness of the analysis sample and the dynamic trends of the treatment effects of interest, here we report the results for entrants to processing trade with an engagement of no more than five consecutive years after entry.[20]

Table 2.3 reports the treatment effects on firm productivity, which are different from the results in Table 2.2. Results in Panel A indicate that for firms that switch from purely domestic sales to processing production, entering into processing trade significantly raises their productivity by an average of 13.5 percent. The growing path is that entrants' productivity increases by 10 percent at entry, then shows a gradually higher level in individual years compared to non-entrants. Whereas the entrants' productivity does not differ significantly from non-entrants eventually from the sixth year after entry, which we report in Table B4. Results in Panel B suggest a similar pattern. The productivity of entrants that have prior experience of ordinary exports is significantly higher than that of non-entrants in the first three post-entry years, while it falls back to a level similar to non-entrants in the follow-up years. These entrants realize productivity gains faster yet obtain fewer productivity spillovers compared to entrants switching from purely domestic sales, which could be because non-exporting firms have relatively low productivity and thus realize productivity gains at a slow pace in processing production.

[19] Industry fixed effect is introduced as some firms in our sample switch between industries.
[20] The results for entrants with one-year engagement till seven-year engagement are reported in Table B4, Table B5, and Table B6.

Table 2.3: Productivity and engagement in processing trade, with PSM-DID method

| | (1a) Ln TFP | (2a) Ln D_TFP$_{t=1}$ | (3a) Ln D_TFP$_{t=2}$ | (4a) Ln D_TFP$_{t=3}$ | (5a) Ln D_TFP$_{t=4}$ | (6a) Ln D_TFP$_{t=5}$ |
|---|---|---|---|---|---|---|
| *Panel A: Sample of treatment group T1 and matched C1* | | | | | | |
| After | 0.135*** | | | | | |
| | (0.020) | | | | | |
| Treated | | 0.100** | 0.074 | 0.202** | -0.014 | 0.288** |
| | | (0.040) | (0.061) | (0.079) | (0.117) | (0.140) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year and industry FE | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | N | N | N | N | N |
| Province FE | N | Y | Y | Y | Y | Y |
| Observations | 35330 | 7560 | 4734 | 3932 | 2561 | 1591 |
| $R^2$ | 0.927 | 0.190 | 0.240 | 0.309 | 0.362 | 0.473 |
| | (1b) Ln TFP | (2b) Ln D_TFP$_{t=1}$ | (3b) Ln D_TFP$_{t=2}$ | (4b) Ln D_TFP$_{t=3}$ | (5b) Ln D_TFP$_{t=4}$ | (6b) Ln D_TFP$_{t=5}$ |
| *Panel B: Sample of treatment group T2 and matched C2* | | | | | | |
| After | 0.052** | | | | | |
| | (0.024) | | | | | |
| Treated | | 0.062* | 0.168** | 0.152** | 0.106 | -0.022 |
| | | (0.034) | (0.068) | (0.076) | (0.163) | (0.217) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year and industry FE | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | N | N | N | N | N |
| Province FE | N | Y | Y | Y | Y | Y |
| Observations | 16295 | 4427 | 2100 | 1602 | 539 | 303 |
| $R^2$ | 0.955 | 0.180 | 0.263 | 0.336 | 0.578 | 0.646 |

*Notes:* TFP is estimated by following Ackerberg et al. (2015). In all regressions, we control for firm age, size, average wage, ownership structure, capital intensity, subsidy, liquidity, and industry concentration. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at firm level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The one-time technology transfer upon entry into processing trade could be a possible explanation for the evolving trends in the productivity of different entrants described in Table 2.3. However, one important implication is that although firms derive productivity spillovers from processing production, these spillovers are not sustainable in the long run. This result implies that the technological content of processing production does not increase to a proportionate extent to the enhancement in productivity of processing firms, suggesting the upper limit of productivity spillovers from processing trade.

Panels A and B in Table 2.4 respectively report the treatment effects on the product varieties and quality of the entrants' ordinary exports. Entry leads to a higher number of product varieties. This facilitation occurs upon entry, followed by a small margin of increase in the subsequent years, and appears to remain stable after the fourth year. Entry also promotes the quality of ordinary products in the entry year, and thereafter the quality improvement of entrants seems to be less than that of non-entrants but the difference is insignificant. Combining the results on product varieties, an interpretation for the results on quality could be that entrants focus on new product development more than on quality improvement for the existing products.

Panels A and B in Table 2.5 respectively report the treatment effects on the number of overseas markets and export revenue of the entrants' ordinary exports. Different from the results in Table 2.2, results in Panel A reveal that engaging in processing trade further enables firms to sell ordinary products in more overseas markets in addition to the improved productivity, product varieties, and product quality. This effect is significant in the entry year and enlarges in the fifth year. Panel B shows that participating in the processing trade is also correlated to an expanding scale of exports for ordinary products: the export revenue significantly increases in the entry year, and this effect expands in the fourth year.

Results in Table 2.3, Table 2.4, and Table 2.5 hence provide more robust details to the results in Table 2.2 and propose the limited spillovers on the productivity and performance of the ordinary exports of processing firms. Although the processing trade endows firms with a close channel of learning from foreign firms, firms cannot achieve continuous growth by participating in processing production, suggesting possible controls over the technological content embodied in the processing trade.

Table 2.4: Product varieties, quality, and engagement in processing trade, with PSM-DID method

| | (1a) Ln Variety | (2a) Ln D_Variety$_{t=1}$ | (3a) Ln D_Variety$_{t=2}$ | (4a) Ln D_Variety$_{t=3}$ | (5a) Ln D_Variety$_{t=4}$ | (6a) Ln D_Variety$_{t=5}$ |
|---|---|---|---|---|---|---|
| *Panel A* | | | | | | |
| After | 0.166*** | | | | | |
| | (0.025) | | | | | |
| Treated | | 0.143*** | 0.097* | 0.187*** | 0.332*** | 0.327* |
| | | (0.027) | (0.051) | (0.066) | (0.120) | (0.168) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year and industry FE | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | N | N | N | N | N |
| Province FE | N | Y | Y | Y | Y | Y |
| Observations | 16201 | 4394 | 2082 | 1587 | 537 | 303 |
| $R^2$ | 0.818 | 0.165 | 0.223 | 0.268 | 0.406 | 0.462 |
| | (1b) Ln Quality | (2b) Ln D_Quality$_{t=1}$ | (3b) Ln D_Quality$_{t=2}$ | (4b) Ln D_Quality$_{t=3}$ | (5b) Ln D_Quality$_{t=4}$ | (6b) Ln D_Quality$_{t=5}$ |
| *Panel B* | | | | | | |
| After | 0.101 | | | | | |
| | (0.131) | | | | | |
| Treated | | 0.320** | -0.008 | -0.466 | -0.452 | -0.667 |
| | | (0.147) | (0.229) | (0.336) | (0.448) | (0.755) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year and industry FE | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | N | N | N | N | N |
| Province FE | N | Y | Y | Y | Y | Y |
| Observations | 14768 | 3870 | 1826 | 1388 | 457 | 269 |
| $R^2$ | 0.771 | 0.147 | 0.209 | 0.283 | 0.370 | 0.479 |

*Notes:* Dependent variables are the indicators for the firm's performance of ordinary exports given in the column heading. In all regressions, we control for firm age, size, average wage, productivity, product quality, ownership structure, capital intensity, subsidy, liquidity, and industry concentration. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at firm level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.5: Overseas markets, export revenue, and engagement in processing trade, with PSM-DID method

| | (1a) Ln Market | (2a) Ln D_Market$_{t=1}$ | (3a) Ln D_Market$_{t=2}$ | (4a) Ln D_Market$_{t=3}$ | (5a) Ln D_Market$_{t=4}$ | (6a) Ln D_Market$_{t=5}$ |
|---|---|---|---|---|---|---|
| *Panel A* | | | | | | |
| After | 0.065*** | | | | | |
| | (0.021) | | | | | |
| Treated | | 0.049* | 0.018 | 0.042 | 0.100 | 0.486** |
| | | (0.025) | (0.047) | (0.062) | (0.123) | (0.197) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year and industry FE | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | N | N | N | N | N |
| Province FE | N | Y | Y | Y | Y | Y |
| Observations | 14768 | 4064 | 1953 | 1493 | 499 | 287 |
| $R^2$ | 0.899 | 0.191 | 0.260 | 0.331 | 0.468 | 0.534 |
| | (1b) Ln OrdExp | (2b) Ln D_OrdExp$_{t=1}$ | (3b) Ln D_OrdExp$_{t=2}$ | (4b) Ln D_OrdExp$_{t=3}$ | (5b) Ln D_OrdExp$_{t=4}$ | (6b) Ln D_OrdExp$_{t=5}$ |
| *Panel B* | | | | | | |
| After | 0.103** | | | | | |
| | (0.050) | | | | | |
| Treated | | 0.130** | -0.154 | -0.109 | 0.487** | 0.577 |
| | | (0.057) | (0.102) | (0.141) | (0.229) | (0.383) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year and industry FE | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | N | N | N | N | N |
| Province FE | N | Y | Y | Y | Y | Y |
| Observations | 14767 | 4064 | 1951 | 1493 | 499 | 287 |
| $R^2$ | 0.822 | 0.197 | 0.272 | 0.317 | 0.488 | 0.558 |

*Notes:* Dependent variables are the indicators for the firm's performance of ordinary exports given in the column heading. In all regressions, we control for firm age, size, average wage, productivity, product quality, ownership structure, capital intensity, subsidy, liquidity, and industry concentration, product varieties, and product quality. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at firm level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

### 2.5.3 Inter-firm spillovers

In this section, we focus on the possible channels through which processing exporters generate spillovers to domestic non-processing firms and the dynamic trends of those spillovers. Considering that foreign-invested firms constitute the primary share of China's processing exporters in the investigation period, we adopt the estimation strategy for the spillovers from inward FDI in estimating the horizontal and backward spillovers from processing exporters. We estimate a variation of the following specification:

$$\begin{aligned} LnY_{it} =& \alpha_0 + \alpha_1 Horizontal_{jt} + \beta_1 Horizontal_{jt} \times Trend_t \\ & + \alpha_2 Backward_{jt} + \beta_2 Backward_{jt} \times Trend_t + C'_{ijt}\gamma \\ & + u_i + u_t + \varepsilon_{it}, \end{aligned} \tag{2.21}$$

where $Y_{it}$ is the outcome of the domestic non-processing firm, and $Horizontal_{jt}$ and $Backward_{jt}$ are the horizontal and backward spillovers from processing exporters, respectively. $Trend_t$ is the variable for linear time trend which equals the year minus the first sample year. Interactions between spillovers and the time trend are exploited to explore the evolving paths of spillovers. Therefore, $\alpha_1$ and $\alpha_2$ represent the spillovers in the base year and $\beta_1$ and $\beta_2$ measure how the spillovers change over time.

According to Haskel et al. (2007), the basic specification (2.21) faces the following estimation issues. One estimation issue is the omitted variables. There may be some industry, region, and firm-specific unobservables that underlie the relationship between the performance of domestic non-processing firms and the presence of processing exporters. For example, production and transportation costs in regions furnished with well-developed infrastructures and close to ports are lower; or mature industry associations can promote firms' production and management efficiencies and knowledge of market demands. These factors facilitate the productivity of domestic non-processing firms and may also attract more foreign investment to engage in processing production or attract more outsourcing orders to domestic processing firms. We use time differencing and fixed effects to tackle the problem of omitted variables. Differencing can remove any time-invariant unobservable factors at the firm, region, and industry levels. Due to the length of our sample periods, we use one-year differencing and introduce industry ($u_j$), province ($u_r$), and year ($u_t$) fixed effects to further control for possible shocks at these levels.

Another estimation issue is endogeneity. Given employing time differencing and fixed effects, to achieve consistent estimates of spillovers, the changes in the presence of processing exporters need to be exogenous to the changes in the outcomes of domestic non-processing firms. Nevertheless, this exogeneity condition may not be satisfied. Foreign investments and outsourcing orders from foreign firms may prefer processing production in regions or industries with generally higher productivity to take advantage of better resources there, such as more skilled labor. Conversely, foreign investments and outsourcing orders may flow to processing production in regions or industries with relatively low productivity, since a large productivity gap with domestic firms can impede the latter's appropriation of spillovers (Crespo and Fontoura, 2007). Considering the materialization of spillovers may take time and our analysis focuses on the trend of spillovers, we use the time-differenced spillovers that enter one-year lagged to address the possible endogeneity problem.[21] Therefore, our approach is to explore whether there is evidence of domestic non-processing firms achieving greater growth but of a declining growth rate in industries where processing production is expanding.[22]

In addition, to better isolate spillovers of interest, we control for market competition by introducing the industry Herfindahl index ($HHI_{jt}$), changes in the firm's market share ($\boldsymbol{\Delta} MShare_{it}$), and industry markups ($IMarkup_{jt}$). Apart from $HHI_{jt}$, the others enter one-year lagged. We also control for a vector of changes in firm characteristics which are employed in previous specifications ($\boldsymbol{\Delta} C'_{it}$). To control for the potential correlation between error terms for firms in the same industry, we cluster standard errors at the 4-digit CIC industry level. The regression specification is therefore given in (2.22) and $Trend_t = year - 2002$.

[21] We instead use the lead values of spillovers in regressions as robustness checks for the validation of our method on dealing with the endogeneity problem. All measures of spillovers are uncorrelated to firm performance except for one interaction between spillovers and the time trend variable, thence we believe we go some way toward resolving this problem. Results are reported in Table B7 in the Appendix.

[22] Lu et al. (2017) propose a DID-based instrumental variable method for studying spillovers from the FDI in China by taking advantage of the plausibly exogenous relaxation of FDI regulations upon China's accession to the WTO. However, the regulations on China's processing trade are not fully consistent with the FDI regulations. For example, the 4-digit industry, chemical pesticides (2631), is an encouraging industry for FDI but a prohibited industry for processing production. More importantly, regulations on the processing trade appear to be endogenously and periodically adjusted in line with the needs of industrial development. We therefore resort to the time differencing and fixed effects model for identifying spillovers from the processing trade.

We separately estimate for domestic ordinary exporters and non-exporting firms.[23]

$$
\begin{aligned}
\boldsymbol{\Delta} LnY_{it} =& \alpha_0 + \alpha_1 \boldsymbol{\Delta} Horizontal_{j,t-1} + \beta_1 \boldsymbol{\Delta} Horizontal_{j,t-1} \times Trend_t \\
&+ \alpha_2 \boldsymbol{\Delta} Backward_{j,t-1} + \beta_2 \boldsymbol{\Delta} Backward_{j,t-1} \times Trend_t \\
&+ \alpha_3 HHI_{jt} + \alpha_4 \boldsymbol{\Delta} MShare_{i,t-1} + \alpha_5 IMarkup_{j,t-1} \\
&+ \boldsymbol{\Delta} C'_{it}\gamma + u_j + u_r + u_t + \varepsilon_{jt}.
\end{aligned} \tag{2.22}
$$

Results are reported in Table 2.6. In columns (1) and (2), we investigate spillovers on the productivity of domestic non-exporting firms and ordinary exporters, respectively. In columns (3)-(6), we investigate spillovers on the performance of ordinary exports. On the productivity of domestic non-exporting firms, we find significant and negative backward spillovers in the year 2002, which gradually mitigate and subsequently turn positive. On the productivity of domestic ordinary exporters, we find significant and positive horizontal spillovers in the year 2002, which nevertheless have a reduced magnitude in the following years. The difference in the channels through which processing firms impact on different domestic non-processing firms may arise from the fact that exporters share more similarities due to the engagement in international sales. Domestic ordinary exporters thus face more compelling spillovers from processing firms within the industry. For example, processing exporters can possibly calibrate the production of domestic ordinary exporters by diffusing information about foreign demands, thereby spreading the latter's fixed costs over a larger volume of output. In contrast, domestic non-exporting firms are more likely to assume the role of upstream suppliers of downstream processing firms and thus face prominent backward spillovers. Spillovers on the performance of ordinary exports other than through productivity are basically null, except for the significantly negative horizontal spillovers on the export revenue in the base year, which subsequently turn positive.[24]

[23] We report the results for spillover variables pooled across all years in Table B8, and the results from omitting control variables in Table B9, in the Appendix.

[24] We also employ an alternative specification where we interact spillovers with year dummies rather than the time trend variable. Results are reported in Table B10. The main conclusions of Table 2.6 are confirmed across the different specifications.

Table 2.6: Spillovers on domestic non-processing firms

| | Non-exporters | Ordinary Exporters | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Dep.Var | **Δ**Ln TFP | **Δ**Ln TFP | **Δ**Ln Variety | **Δ**Ln Quality | **Δ**Ln Market | **Δ**Ln OrdExp |
| **Δ**Horizontal | 0.086 | 0.858** | -0.242 | -1.116 | -0.251 | -2.276*** |
| | (0.168) | (0.400) | (0.405) | (2.484) | (0.329) | (0.689) |
| **Δ**Horizontal × Trend | -0.050 | -0.170* | 0.122 | 0.383 | 0.084 | 0.704*** |
| | (0.046) | (0.101) | (0.113) | (0.642) | (0.087) | (0.184) |
| **Δ**Backward | -3.264*** | -0.282 | 0.960 | -4.895 | -0.870 | -4.518 |
| | (1.042) | (1.948) | (1.727) | (8.902) | (2.083) | (3.827) |
| **Δ**Backward × Trend | 0.788*** | -0.032 | -0.122 | 2.672 | 0.331 | 1.286 |
| | (0.266) | (0.455) | (0.447) | (2.424) | (0.584) | (1.054) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y | Y | Y |
| Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 325804 | 20981 | 16805 | 14513 | 14513 | 14513 |
| $R^2$ | 0.107 | 0.120 | 0.034 | 0.034 | 0.225 | 0.169 |

*Notes:* Dependent variables given in each column heading are the difference in the firm's outcomes. In all regressions, we control for industry concentration, industry markup, the firm's market share, age, size, average wage, capital intensity, subsidy, and liquidity. In columns (3)-(6), we further control for productivity; in columns (5) and (6), log product varieties and log product quality are also controlled. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at 4-digit industry level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

## 2.6 Possible explanations for the descending inter-firm spillovers

Mechanisms behind the changes of inter-firm spillovers can be classified into internal and external causes by source. External causes refer to ones that induce the endogenous fluctuations in the positive externalities of processing exporters or interfere with the diffusion process of knowledge. In comparison, internal causes refer to the changes inside learning firms that discourage them from taking advantage of the knowledge diffusion of processing exporters. Based on these two aspects, there are three possibilities for the decreasing pattern of productivity spillovers observed in section 2.5.3.

One explanation is that the pattern is only evoked by internal mechanisms. Processing trade brings stable knowledge to China, while domestic non-processing firms progress rapidly through spillovers and benefit less from the presence of processing firms afterward. The second explanation is specific to external mechanisms. Domestic non-processing firms have only minor improvement through spillovers, presumably due to incomplete absorptive capacity. However, the positive externalities of processing exporters decrease relatively faster, possibly resulting from the controls of foreign firms on spillovers that restrict the channels of diffusion or the technological content of processing production. For instance, foreign firms may outsource a lower number of product varieties for processing or assembly in China to alleviate the imitation of their products by Chinese firms. In this case, domestic non-processing firms retain a high willingness to learn from processing exporters while the available information decreases. The third explanation combines the former two. Learning firms have achieved more than modest progress through spillovers, and the positive externalities have also been periodically adjusted.

Since we do not hold information that can appropriately capture the knowledge of processing production (e.g., ideal indicators would be which stages of the production process are outsourced, or the turnover rates of the specialists of processing firms), it is less feasible to examine the external causes. Namely, the impacts of domestic non-processing firms' progress on the technological substance of processing production. We therefore attempt a preliminary check of the internal causes through several exercises on how domestic non-processing firms' rising innovation activities change the way in which they utilize spillovers.

Innovation activities inside a firm are mainly of two sorts, process innovation, and product innovation. Process innovation often leads to higher production efficiency as a result of optimized production technology, and product innovation gives rise to new products or products with new features (Cassiman et al., 2010). We use the firm's R&D expenditure to proxy its comprehensive research capability, supplemented by the new product output as the specific measure of product innovation. If intense innovation activities reduce the firm's learning willingness for processing exporters, they are supposed to have a downward impact on the spillovers on firm performance. Innovation activities are otherwise supposed to amplify the effects of spillovers if they promote the firm's absorption and utilization for externalities while not impeding the willingness to learn. Innovation activities will not significantly interact with spillovers if they do not even improve the absorption of spillovers or if the spillovers are insignificant.

### 2.6.1 R&D activities and the utilization of spillovers

We examine the impact of the firm's R&D activities on its way of utilizing spillovers with the following specification:

$$\begin{aligned}\boldsymbol{\Delta} LnY_{it} =& \alpha_0 + \alpha_1 \boldsymbol{\Delta} Horizontal_{j,t-1} + \alpha_2 \boldsymbol{\Delta} Horizontal_{j,t-1} \times RD_{it} \\ & + \alpha_3 \boldsymbol{\Delta} Backward_{j,t-1} + \alpha_4 \boldsymbol{\Delta} Backward_{j,t-1} \times RD_{it} + \alpha_5 RD_{it} \\ & + \alpha_6 HHI_{jt} + \alpha_7 \boldsymbol{\Delta} MShare_{i,t-1} + \alpha_8 IMarkup_{j,t-1} + \boldsymbol{\Delta} C'_{it}\gamma \\ & + u_j + u_r + u_t + \varepsilon_{jt}. \end{aligned} \tag{2.23}$$

where $RD_{it}$ is the R&D intensity of firm $i$ in year $t$, measured by the percentage of R&D expenditure in revenue. Since ASIF only reports R&D expenditures for 2005–2007, we resort to data for this period. Considering that the firm's R&D activities are likely to endogenously respond to the presence of processing firms, we employ the R&D intensity of the firm in the year 2004 for those that enter the sample before 2004, and the R&D intensity in the entry year into the sample for those that enter after 2004. Spillover variables that constitute interactions are demeaned.[25]

Results are reported in Table 2.7. During the period 2005-2007, the R&D engagement of domestic non-processing firms does not contribute to productivity improvement. A larger presence of processing firms in the downstream industries, however, stimulates the R&D activities of domestic non-exporting firms to drag down productivity, apart from which, no other significant interactions on productivity between spillovers and R&D engagement are found. In terms of the effects on product varieties, we also find significant interactions between R&D engagement and both horizontal and backward spillovers: more processing firms within the industry can promote product varieties yet this effect is undermined by R&D activities, implying that those R&D activities are product-oriented and quickly absorb the relevant information embodied in horizontal spillovers. Given the contribution of product varieties to export performance, the gradually relieved negative horizontal spillovers on export revenue observed in Table 2.6 is thereby explained. In comparison, backward spillovers significantly amplify the outcomes of R&D activities on product varieties, suggesting that a larger presence of downstream processing firms facilitates the R&D engagement of domestic upstream ordinary exporters aiming at product varieties. After controlling for the changes in productivity, product varieties, and quality, a deeper R&D engagement contributes to better international sales.

As the exported ordinary products are the subsets of products sold in the domestic market (Kee and Tang, 2016), backward spillovers on the product vari-

[25] We report the results from omitting interactions in Table B11.

Table 2.7: R&D engagement and inter-firm spillovers

| | Non-exporters | Ordinary Exporters | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Dep.Var | $\boldsymbol{\Delta}$Ln TFP | $\boldsymbol{\Delta}$Ln TFP | $\boldsymbol{\Delta}$Ln Variety | $\boldsymbol{\Delta}$Ln Quality | $\boldsymbol{\Delta}$Ln Market | $\boldsymbol{\Delta}$Ln OrdExp |
| RD | 0.001 | 0.001 | 0.003 | 0.064 | 0.014*** | 0.033** |
| | (0.001) | (0.007) | (0.003) | (0.045) | (0.004) | (0.015) |
| $\boldsymbol{\Delta}$Horizontal | -0.103 | 0.121 | 0.384** | 1.208 | 0.146 | 0.184 |
| | (0.083) | (0.148) | (0.162) | (1.308) | (0.133) | (0.345) |
| RD × $\boldsymbol{\Delta}$Horizontal | 0.018 | 0.141 | -0.308** | -0.608 | -0.073 | 0.180 |
| | (0.036) | (0.106) | (0.133) | (0.673) | (0.090) | (0.222) |
| $\boldsymbol{\Delta}$Backward | 0.365 | -0.421 | -0.341 | 2.734 | 0.594 | 1.428 |
| | (0.299) | (0.664) | (0.836) | (5.032) | (0.765) | (2.076) |
| RD × $\boldsymbol{\Delta}$Backward | -0.411*** | -0.367 | 1.240** | 5.951 | 0.148 | 1.690 |
| | (0.092) | (0.578) | (0.486) | (5.465) | (0.512) | (1.593) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y | Y | Y |
| Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 219894 | 16056 | 13143 | 11405 | 11405 | 11405 |
| $R^2$ | 0.131 | 0.146 | 0.040 | 0.042 | 0.218 | 0.171 |

*Notes:* Dependent variables given in each column heading are the difference in the firm's outcomes. In all regressions, we control for industry concentration, industry markup, the firm's market share, age, size, average wage, capital intensity, subsidy, and liquidity. In columns (3)-(6), we further control for productivity; in columns (5) and (6), log product varieties and log product quality are also introduced. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at 4-digit industry level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

eties of ordinary exports suggest possibly a similar effect on the product varieties of domestic non-exporting firms. The results in columns (1) and (3) of Table 2.7 hence provide a potential explanation for the negative backward productivity spillovers depicted in section 2.5.3. Processing firms convey product-related information and generate diverse demands for inputs, thereby steering domestic upstream non-exporting firms toward product development rather than productivity enhancement. Domestic non-exporting firms' gradual technological progress reduces the productivity costs of new product exploration and thereby mitigates the disruption of product-oriented R&D to productivity. Whereas for the descending trend in horizontal productivity spillovers described in Table 2.7, we do not find robust evidence of domestic ordinary exporters' R&D having reduced their productivity gains from horizontal spillovers.

### 2.6.2 New product development and the utilization of spillovers

To investigate how the new product exploration alters the firm's utilization of spillovers, we adapt specification (2.23) by replacing $RD_{it}$ with $NEW_{it}$, the intensity of the new product development of firm $i$ in year $t$, measured by the percentage of output for new products in total output. The records of new product output in ASIF are unavailable for the year 2004, and we resort to years of available records. Given the possible endogeneity, we employ the new product intensity of the firm in its entry year into the sample. For those entering the sample in the year 2004, we use the new product intensity in 2005. Other aspects remain the same. Spillover variables that constitute interactions are demeaned.[26]

Table 2.8 reports the results. New product development has neither a significant and direct effect on the productivity of domestic non-processing firms nor an indirect effect through interacting with spillovers. Whereas firms reporting a larger share of new products seem to deliver slightly fewer varieties of ordinary products to international markets. The only significant interaction is the effect on the number of overseas markets, thus demonstrating that backward spillovers can stimulate firms to reach more foreign markets by offering a wider range of new products.

Table 2.8: New product development and inter-firm spillovers

| | Non-exporters | Ordinary Exporters | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Dep.Var | **Δ**Ln TFP | **Δ**Ln TFP | **Δ**Ln Variety | **Δ**Ln Quality | **Δ**Ln Market | **Δ**Ln OrdExp |
| NEW | 0.000 | 0.000 | -0.001* | 0.001 | -0.000 | -0.001 |
| | (0.000) | (0.000) | (0.000) | (0.002) | (0.000) | (0.001) |
| **Δ**Horizontal | -0.067 | 0.274* | 0.198 | 0.510 | -0.010 | -0.148 |
| | (0.099) | (0.153) | (0.158) | (1.079) | (0.131) | (0.321) |
| NEW × **Δ**Horizontal | 0.001 | 0.004 | 0.005 | -0.032 | 0.002 | 0.014 |
| | (0.004) | (0.006) | (0.006) | (0.075) | (0.004) | (0.011) |
| **Δ**Backward | -0.828** | -0.596 | 0.426 | 5.382 | 0.123 | 0.151 |
| | (0.381) | (0.721) | (0.857) | (4.160) | (0.614) | (1.965) |
| NEW × **Δ**Backward | -0.007 | 0.045 | -0.053 | -0.300 | 0.048* | -0.001 |
| | (0.012) | (0.061) | (0.040) | (0.253) | (0.029) | (0.065) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y | Y | Y |
| Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 325788 | 20979 | 14511 | 14511 | 14511 | 14511 |
| $R^2$ | 0.107 | 0.120 | 0.038 | 0.034 | 0.225 | 0.168 |

*Notes:* Dependent variables given in each column heading are the difference in the firm's outcomes. In all regressions, we control for industry concentration, industry markup, the firm's market share, age, size, average wage, capital intensity, subsidy, and liquidity. In columns (3)-(6), we further control for productivity; in columns (5) and (6), log product varieties and log product quality are also introduced. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at 4-digit industry level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

To sum up, according to the results in Table 2.7 and Table 2.8, we do not find robust signs for the innovation activities of domestic ordinary exporters having reduced their productivity gains from horizontal spillovers. Therefore, the shrink-

[26] We report the results from omitting interactions in Table B12.

ing horizontal productivity spillovers potentially imply external mechanisms, such as the cutback of positive externalities of processing firms within the industry. Our findings thus suggest that ignoring the changing trend of spillovers will underestimate the role of the processing trade in the development of Chinese firms and foreign trade, and prevent us from discerning foreign firms' possible strategic controls over spillovers.

### 2.6.3 Effects of the varieties of processing products

The above analysis is supportive of the presence of processing exporters being linked to the choices of domestic non-processing firms in their product development, yet the channel behind is still unclear. Among multiple factors affecting trade and economic growth, product variety is argued to play a central role (Broda and Weinstein, 2006). Domestic firms can obtain productivity gains or expand product scope by using more varieties of imported inputs (Goldberg et al., 2010), or can benefit from sourcing from upstream suppliers that also supply downstream FDI firms, as those suppliers can often improve products via the supply linkages with FDI firms (Kee, 2015). We therefore propose that the varieties of processing products are a potential influencer of the product development of domestic non-processing firms and we explore the possible spillovers from processing exporters via product varieties. Similar to the horizontal and backward spillovers studied above, we consider the effects of the varieties of processing products (hereafter, the variety effects, for concision) within the industry (horizontal) and in downstream industries (backward) on the quality and varieties of ordinary products of domestic non-processing firms.

As ASIF only reports the primary belonging industries of firms rather than their product categories, we use the product information recorded in CCTS. We classify all exported products into 19 UN industry sectors according to their HS 2-digit codes.[27] The horizontal variety effects ($Horiz\_Variety$) in each sector are measured with the number of different HS6 products exported under the processing trade regime. To calculate the backward variety effects ($Back\_Variety$), we need to determine the upstream-downstream relationships for industries classified by the

[27] These sectors are: (1) live animals (HS2 codes between 1 and 5); (2) vegetables (6-14); (3) animal or vegetable oil (15); (4) beverage and spirit (16-24); (5) mineral products (25-27); (6) chemical products (28-38); (7) plastics and rubber (39-40); (8) raw hides and skins (41-43); (9) wood and articles (44-46); (10) pulp of wood (47-49); (11) textiles (50-63); (12) footwear and headgear, etc. (64-67); (13) stone, plaster, cement, etc. (68-70); (14) precious metals (71); (15) base metals (72-83); (16) machinery, mechanic, electronic equipment (84-85); (17) vehicles and aircraft (86-89); (18) optical, photographic, etc. (90-92); (20) miscellaneous manufacturing (94-96).

HS code system. We thus draw on the method of Kee and Tang (2016) to match the IO industries in the Chinese Input-Out Table with HS 6-digit codes (revision 2002) and establish the concordance between IO industries and UN industry sectors by HS 6-digit codes. Next, we add up the values of intermediate inputs for each pair of upstream-downstream relationships and recalculate the IO coefficients between the UN industry sectors. Based on the consumption coefficients, the weighted averages of varieties of processed finished products in the downstream sectors are used as the proxy for the backward variety effects facing firms in each sector. Since most exporters are multi-product producers, we match the variety effects at the UN sectoral level with firm-HS6 product pairs and compute the firm-level weighted average horizontal and backward variety effects with the firm's export share in each sector.

We estimate the following specification to study the horizontal and backward variety effects,

$$\begin{aligned} \boldsymbol{\Delta} LnY_{it} =& \alpha_0 + \alpha_1 \boldsymbol{\Delta} Horiz\_Variety_{j,t-1} + \alpha_2 \boldsymbol{\Delta} Back\_Variety_{j,t-1} + X'_{it}\gamma \\ & + u_j + u_r + u_t + \varepsilon_{jt}. \end{aligned} \tag{2.24}$$

Where $Y_{it}$ is the quality and varieties of ordinary exports shipped by domestic non-processing firms, and $X'_{it}$ is the same set of control variables used in the specification (2.23) for the investigation on product varieties and quality.

Results are reported in Table 2.9. Column (1) indicates that the varieties of ordinary products are negatively correlated with the varieties of processing products within the industry, and positively correlated with the varieties of processing products in the downstream industries. By contrast, column (2) suggests that the quality of ordinary products is positively correlated with the varieties of processing products within the industry, and negatively correlated with the varieties of processing products in the downstream industries. These results are compatible with those in Table 2.7, for which the interpretation is that processing exports and ordinary exports in the same industry are substitutes in international markets. Therefore, the assembly for a larger scope of foreign substitutes transferred to China will prompt domestic ordinary exporters to enhance their competitiveness and reduce competition by differentiating their production. Compared to quality improvement, the development and production of new products induce intensive investments (Bhaskaran and Krishnan, 2009), such as opening a new production line or organizing employee training for the new production process, and bear more risks. Domestic ordinary exporters thereby seek differentiation with respect to foreign firms in terms of quality rather than product varieties. The production of a wider scope of processing products in the downstream industries will generate more diverse demands for intermediate inputs, thereby encouraging domestic upstream suppliers to focus on new product development instead of the quality improvement of the existing products.

Table 2.9: Ordinary product development of domestic non-processing firms and the varieties of processing products

| | **Δ**Ln Variety<br>(1) | **Δ** Ln Quality<br>(2) |
|---|---|---|
| **Δ**Horiz_Variety | -0.297*** | 0.969* |
| | (0.076) | (0.494) |
| **Δ**Back_Variety | 0.278* | -2.229** |
| | (0.169) | (1.001) |
| Control variables | Y | Y |
| Year FE | Y | Y |
| Industry FE | Y | Y |
| Province FE | Y | Y |
| Observations | 10573 | 9378 |
| $R^2$ | 0.265 | 0.274 |

*Notes:* Dependent variables given in each column heading are the differences in the log product varieties and log quality of ordinary exports from domestic non-processing firms, respectively. In all regressions, we control for industry concentration, industry markup, the firm's market share, age, size, productivity, average wage, capital intensity, subsidy, and liquidity. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at 4-digit industry level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

## 2.7 Concluding remarks

China's foreign trade achieved a deeper integration into global value chains through processing trade after joining the WTO. After absorbing a large amount of inward FDI, the Chinese processing trade has realized rapid development and created good opportunities for domestic firms to learn from foreign firms. While facing Chinese firms' progressing in independent innovations and the rise of Chinese national brands, foreign firms gradually take more critical measures to prevent competition and preempt future advantages, which will inevitably reduce the learning space for Chinese firms.

To explain the above logic, we begin by studying the competition and cooperation between a firm in a developed country and Chinese firms through an outsourcing model which incorporates technology spillovers. We demonstrate that the increasing competitiveness of Chinese firms, stemming from spillovers, will arouse the countermeasures of foreign firms against spillovers.

Secondly, we provide empirical evidence describing the dynamic trends of the intra-firm, horizontal, and backward spillovers from processing trade. We find significant and positive intra-firm spillovers on processing firms' productivity and the varieties of ordinary exports. The spillovers on productivity are nevertheless only significant in the short run, and spillovers on product varieties gradually remain at a stable level, implying the upper limit of knowledge transfers from processing production.

We also find positive horizontal productivity spillovers on domestic ordinary exporters and negative backward productivity spillovers on domestic non-exporting firms in the base year (2002). Both kinds of spillovers decrease in scale in the following years owing to different reasons. We find that processing firms spread product and production information and generate diverse demands for inputs, steering domestic upstream non-exporting firms toward product development instead of productivity enhancement. This negative effect on productivity is mitigated by domestic non-exporting firms' technological advancement which saves the productivity costs of new product exploration. The reduction in horizontal productivity spillovers are potentially associated with the shrinking positive externalities of processing exporters which potentially arise from foreign firms' controls over spillovers.

This study has important policy implications. The mutual constraints between the continuous expansion of the technology frontiers of Chinese firms and the spillovers from processing trade indicate that the new normal of the contribution of processing trade to China's technology progress began to take shape before 2007. This means the strategy of acquiring technology and knowledge through trade openness to boost economic growth will gradually become ineffective, which will lead to the gradual disappearance of China's late-developing advantage. Facing this challenge, developing countries like China should focus on implementing innovation-driven strategies and promptly developing new engines for economic growth.

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## 2.8 Appendix

**Proof of Corollary 2.1**: We express the first-order condition function of the profit maximization of firm $A$ as

$$F = (1-\sigma)\ \Omega|_{\phi=\phi^*} = 0, \tag{B1}$$

$$\Omega = \frac{\partial ln(p^{AO}(\phi))}{\partial\phi} - \frac{\partial ln(P^{O}(\phi))}{\partial\phi}, \tag{B2}$$

To prove corollary 2.1, we need to prove three lemmas as follows.

**Lemma 2.1.** *Without outsourcing occurs, the first-order condition function $F$ is positive, that is, $F|_{\phi=0} > 0$.*

*Proof.* Because $1-\sigma < 0$, so $F|_{\phi=0} > 0 \iff \Omega|_{\phi=0} < 0$. Compute the first-order derivatives of $ln(p^{AO}(\phi))$, $ln(p^{BO}(\phi))$ and $ln(p^{NO_j}(\phi)), j = 1,\dots,n$ with respect to $\phi$ as

$$\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial\phi} = \frac{e^{\phi}\left(w\tau-1\right)}{w\tau\left(e^{\phi}-1\right)+\left(e-e^{\phi}\right)}, \tag{B3}$$

$$\frac{\partial ln\left(p^{BO}(\phi)\right)}{\partial\phi} = \frac{e^{\delta\phi}-e^{\lambda\phi}}{\frac{e^{\phi\delta}-1}{\delta}+\frac{e^{\lambda}-e^{\lambda\phi}}{\lambda}}, \tag{B4}$$

$$\frac{\partial ln\left(p^{NO_j}(\phi)\right)}{\partial\phi} = \frac{e^{\delta'\phi}-e^{\lambda\phi}}{\frac{e^{\phi\delta'}-1}{\delta}+\frac{e^{\lambda}-e^{\lambda\phi}}{\lambda}}, j = 1,\dots,n. \tag{B5}$$

As $w\tau < 1$, $1 \le \delta \le \lambda$ and $1 \le \delta' \le \lambda$, so $\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial\phi} < 0$, $\frac{\partial ln\left(p^{BO}(\phi)\right)}{\partial\phi} < 0$ and $\frac{\partial ln\left(p^{NO_j}(\phi)\right)}{\partial\phi} < 0, j = 1,\dots,n$.

Calculate the first-order derivative of $ln\left(P^{O}(\phi)\right)$ with respect to $\phi$ as

$$\begin{aligned}\frac{\partial ln\left(P^{O}(\phi)\right)}{\partial\phi} =& M^{AO}(\phi)\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial\phi} + M^{BO}(\phi)\frac{\partial ln\left(p^{BO}(\phi)\right)}{\partial\phi} \\ &+ \sum_{j=1}^{n} M^{NO_j}(\phi)\,\frac{\partial ln\left(p^{NO_j}(\phi)\right)}{\partial\phi}.\end{aligned} \tag{B6}$$

As $\frac{\partial ln\left(P^{O}(\phi)\right)}{\partial\phi}$ is a weighted average of $\frac{\partial ln\left(P^{iO}(\phi)\right)}{\partial\phi}, i = A, B, N_1,\dots,N_n$ with respect to market share $M^{iO}(\phi)$, hence $\frac{\partial ln\left(P^{O}(\phi)\right)}{\partial\phi} < 0$.

Substitute $\phi = 0$ into equation (B3), (B4), and (B5), we have

$$\left.\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right|_{\phi=0} = \frac{w\tau - 1}{e-1}, \tag{B7}$$

$$\left.\frac{\partial ln\left(p^{BO}(\phi)\right)}{\partial \phi}\right|_{\phi=0} = \left.\frac{\partial ln\left(p^{NO_j}(\phi)\right)}{\partial \phi}\right|_{\phi=0} = 0, j = 1, \dots, n. \tag{B8}$$

On this basis, simplify equation (B6) we have $\left.\frac{\partial ln\left(p^{O}(\phi)\right)}{\partial \phi}\right|_{\phi=0} = M^{AO}(\phi)\left.\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right|_{\phi=0}$. $0 < M^{AO}(\phi) < 1$ leads to

$$\left.\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right|_{\phi=0} < \left.\frac{\partial ln\left(p^{O}(\phi)\right)}{\partial \phi}\right|_{\phi=0} < 0. \tag{B9}$$

Hence $\Omega|_{\phi=0} < 0,\ F|_{\phi=0} > 0$ is proved. □

**Lemma 2.2.** *In the range of $\phi \in [0,1]$, $\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}$ and $\frac{\partial ln\left(p^{O}(\phi)\right)}{\partial \phi}$ are decreasing in $\phi$.*

*Proof.* Compute the first-order derivative of equation (B3) with respect to $\phi$ as

$$\frac{\partial^2 ln\left(p^{AO}(\phi)\right)}{\partial \phi^2} = \frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\left(1 - \frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right). \tag{B10}$$

Notice that $\frac{\partial^2 ln\left(p^{AO}(\phi)\right)}{\partial \phi^2} < 0$ as $\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi} < 0$.

Compute the first-order derivative of equation (B4) with respect to $\phi$ as

$$\frac{\partial^2 ln\left(p^{BO}(\phi)\right)}{\partial \phi^2} = \frac{\delta e^{\delta\phi} - \lambda e^{\lambda\phi}}{\frac{e^{\phi\delta}-1}{\delta} + \frac{e^{\lambda}-e^{\lambda\phi}}{\lambda}} - \left(\frac{\partial ln\left(p^{BO}(\phi)\right)}{\partial \phi}\right)^2. \tag{B11}$$

Because $\delta e^{\delta\phi} - \lambda e^{\lambda\phi} < e^{\delta\phi} - e^{\lambda\phi} < 0$, hence $\frac{\partial^2 ln\left(p^{BO}(\phi)\right)}{\partial \phi^2} < 0$. Likewise, we have $\frac{\partial^2 ln\left(p^{NO_j}(\phi)\right)}{\partial \phi^2} < 0, j = 1, \dots, n$.

Compute the first-order derivative of equation (B6) with respect to $\phi$ as

$$\frac{\partial^2 ln\left(p^{O}(\phi)\right)}{\partial \phi^2} = \sum M^{iO}(\phi)\frac{\partial^2 ln\left(p^{iO}(\phi)\right)}{\partial \phi^2} + \sum \frac{\partial M^{iO}(\phi)}{\partial \phi}\frac{\partial ln\left(p^{iO}(\phi)\right)}{\partial \phi},$$
$$i = A, B, N_1, \dots, N_n, \tag{B12}$$

where

$$\frac{\partial M^{iO}(\phi)}{\partial \phi} = (1-\sigma) M^{iO}(\phi) \left( \frac{\partial ln\left(p^{iO}(\phi)\right)}{\partial \phi} - \sum M^{jO}(\phi) \frac{\partial ln\left(p^{jO}(\phi)\right)}{\partial \phi} \right),$$
$$i = A, B, N_1, \ldots, N_n. \quad \text{(B13)}$$

Substitute equation (B13) into equation (B12) and simplify we have

$$\frac{\partial^2 ln\left(p^{O}(\phi)\right)}{\partial \phi^2} = \frac{1-\sigma}{n+2} \sum \left[ M^{iO}(\phi) \sum M^{jO}(\phi) \left( \frac{\partial ln\left(p^{iO}(\phi)\right)}{\partial \phi} - \frac{\partial ln\left(p^{jO}(\phi)\right)}{\partial \phi} \right)^2 \right]$$
$$+ \sum M^{iO}(\phi) \frac{\partial^2 ln\left(p^{iO}(\phi)\right)}{\partial \phi^2}, i = A, B, N_1, \ldots, N_n, i \neq j. \quad \text{(B14)}$$

As $1-\sigma < 0$, so the first term in the right hand side of equation (B14) is negative. Combing $\frac{\partial^2 ln\left(p^{iO}(\phi)\right)}{\partial \phi^2} < 0, i = A, B, N_1, \ldots, N_n$, so $\frac{\partial^2 ln\left(p^{O}(\phi)\right)}{\partial \phi^2} < 0$. □

**Lemma 2.3.** *The second-order condition of the profit maximization, that is,* $\frac{\partial F}{\partial \phi}$*, its sign depends on the substitutability (i.e.,* $\sigma$*), Chinese labor cost (i.e.,* $w$*) and the extent to which Chinese firms utilize technology spillovers (i.e.,* $\delta$ *and* $\delta'$*).*

*Proof.* $\frac{\partial F}{\partial \phi} = (1-\sigma)\left( \frac{\partial^2 ln\left(p^{AO}(\phi)\right)}{\partial \phi^2} - \frac{\partial^2 ln\left(p^{O}(\phi)\right)}{\partial \phi^2} \right)$. Define $K = \frac{\partial^2 ln\left(p^{AO}(\phi)\right)}{\partial \phi^2} - \frac{\partial^2 ln\left(p^{O}(\phi)\right)}{\partial \phi^2}$. Simplify $K$ with equation (B14) as

$$K = \frac{\sigma-1}{n+2} \sum \left[ M^{iO}(\phi) \sum M^{jO}(\phi) \left( \frac{\partial ln\left(p^{iO}(\phi)\right)}{\partial \phi} - \frac{\partial ln\left(p^{jO}(\phi)\right)}{\partial \phi} \right)^2 \right]$$
$$+ \sum M^{zO}(\phi) \frac{\partial^2 ln\left(p^{AO}(\phi)\right)}{\partial \phi^2} - \sum M^{zO}(\phi) \frac{\partial^2 ln\left(p^{zO}(\phi)\right)}{\partial \phi^2},$$
$$i, j = A, B, N_1, \ldots, N_n, i \neq j; z = B, N_1, \ldots, N_n. \quad \text{(B15)}$$

The first term of equation (B15) is larger than zero, and the sign of the second term depends on the relative size of $\frac{\partial^2 ln\left(p^{AO}(\phi)\right)}{\partial \phi^2}$ and $\frac{\partial^2 ln\left(p^{zO}(\phi)\right)}{\partial \phi^2}$. To determine the sign of the second term, we compute the derivatives of $\frac{\partial^2 ln\left(p^{AO}(\phi)\right)}{\partial \phi^2}$ with respect to $w\tau$ (i.e., represents the unit labor cost of the outsourced task, herein considered as a whole), $\delta$ and $\delta'$, respectively as

$$\partial\left[\frac{\partial^2 ln\left(p^{AO}(\phi)\right)}{\partial\phi^2}\right]/\partial w\tau=\frac{-e^{\phi}\left[(w\tau-1)\left(e^{\phi+1}-e^{\phi}\right)+(w\tau+1)\,e-w\tau-e^2\right]}{\left[e-e^{\phi}+w\tau\left(e^{\phi}-1\right)\right]^3},\tag{B16}$$

$$\partial\left[\frac{\partial^2 ln\left(p^{AO}(\phi)\right)}{\partial\phi^2}\right]/\partial\delta=\partial\left[\frac{\partial^2 ln\left(p^{AO}(\phi)\right)}{\partial\phi^2}\right]/\partial\delta'=0,\tag{B17}$$

where the denominator of equation (B16) is larger than zero and the nominator is increasing in $\phi$ and decreasing in $w\tau$. Hence the nominator obtains the minimum as $1-2e+e^2>0$ given $\phi=0$, $w\tau=1$. Therefore, $\partial\left[\frac{\partial^2 ln\left(p^{AO}(\phi)\right)}{\partial\phi^2}\right]/\partial w\tau>0$.

$w$ and $\delta'$ are not in the expression of $\frac{\partial^2 ln\left(p^{BO}(\phi)\right)}{\partial\phi^2}$, so $\partial\left[\frac{\partial^2 ln\left(p^{BO}(\phi)\right)}{\partial\phi^2}\right]/\partial w=0$ and $\partial\left[\frac{\partial^2 ln\left(p^{BO}(\phi)\right)}{\partial\phi^2}\right]/\partial\delta'=0$. While $\delta$ represents the technological gap between firm $B$ and firm $A$ when technology spillovers exist. The smaller $\delta$ means the smaller the technology gap, that is, the stronger the learning and absorbing ability of firm $B$ on technology spillovers. At this time, the cost and price of firm $B$ falls faster with an increasing $\phi$, so $\partial\left[\frac{\partial^2 ln\left(p^{BO}(\phi)\right)}{\partial\phi^2}\right]/\partial\delta>0$. Likewise, we have $\partial\left[\frac{\partial^2 ln\left(p^{NO_j}(\phi)\right)}{\partial\phi^2}\right]/\partial w=\partial\left[\frac{\partial^2 ln\left(p^{NO_j}(\phi)\right)}{\partial\phi^2}\right]/\partial\delta=0,\partial\left[\frac{\partial^2 ln\left(p^{NO_j}(\phi)\right)}{\partial\phi^2}\right]/\partial\delta'>0, j=1,\ldots,n$.

Based on the above points and combined with numerical simulation tests, it can be seen that when outsourcing brings a certain degree of cost savings ($w\tau$ is higher than a certain threshold), and Chinese firms have a high degree of utilizing technology spillovers ($\delta$ and $\delta'$ are low), the larger the second term of equation (B15). At this time, if the substitution of Chinese and foreign products is stronger (larger $\sigma$), and thus the first term of equation (B15) is larger, then $K$ is larger than zero, that is, the second-order condition of profit maximization is satisfied, $\frac{\partial F}{\partial\phi}<0$; otherwise, the second-order condition of profit maximization is not guaranteed to be satisfied. □

Next we move on to prove corollary 2.1.

(1) Given $F|_{\phi=1}<0$ when the foreign contractor outsources all production tasks to the Chinese firm, if $w>w_{min}$, $w_{min}=f(\delta,\lambda)\in[0,1]$, then combining lemma 1 (i.e., $F|_{\phi=0}>0$) and the mean value theorem we know that in the interval $\phi\in(0,1)$, there must be a $\phi^*$ that makes $F|_{\phi=\phi^*}=0$. That is, the first-order condition of profit maximization is proved.

Besides, combining with lemma 2.3, $\frac{\partial F}{\partial \phi} < 0$ holds true given a large $\sigma$ and small $\delta$ and $\delta'$. In this case, the second-order condition of profit maximization is satisfied with $\phi^*$ as well. As a result, $\phi^* \in (0,1)$ must be the only point of intersection and firm $A$'s profit maximization has only one interior solution. Otherwise, $\frac{\partial F}{\partial \phi} > 0$ and $\phi^*$ is the minimum point. In this case firm $A$' profit maximization has only corner solutions.

(2) Given $F|_{\phi=1} \geq 0$ when the foreign contractor outsources all production tasks to the Chinese firm, then combining with lemma 2.1 and lemma 2.2, there is no point of intersection between $\frac{\partial ln(p^{AO}(\phi))}{\partial \phi}$ and $\frac{\partial ln(P^{O}(\phi))}{\partial \phi}$ in the interval $\phi \in (0,1)$. That is, firm $A$' profit maximization has only corner solutions.

**Proof of Corollary 2.2:** By the implicit function theorem and $\left.\frac{\partial F}{\partial \phi}\right|_{\phi=\phi^*} < 0$ (i.e., the second-order condition of profit maximization), we have $\left.\frac{\partial \phi^*}{\partial \tau}\right|_{\phi=\phi^*} = \left.-\frac{\partial F}{\partial \tau}/\frac{\partial F}{\partial \phi}\right|_{\phi=\phi^*}$. As $F = (1-\sigma)\,\Omega$, and $1-\sigma < 0$, to prove corollary 2.2, we need to prove $\left.\frac{\partial \phi^*}{\partial \tau}\right|_{\phi=\phi^*} < 0 \iff \left.\frac{\partial \Omega}{\partial \tau}\right|_{\phi=\phi^*} > 0$, equivalent to $\partial\left[\left.\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*}\right]/\partial \tau > \partial\left[\left.\frac{\partial ln\left(p^{O}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*}\right]/\partial \tau$.

When $\phi^* \in (0,1)$, compute the first-order derivative of $\left.\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*}$ with respect to $\tau$ as

$$\partial\left[\left.\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*}\right]/\partial \tau = \frac{e^{\phi^*}w\,(e-1)}{\left[\left(e-e^{\phi^*}\right)+\tau w\left(e^{\phi^*}-1\right)\right]^2} > 0. \tag{B18}$$

Likewise, compute the first-order derivative of $\left.\frac{\partial ln\left(p^{O}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*}$ with respect to $\tau$ as

$$\begin{aligned}\partial\left[\left.\frac{\partial ln\left(p^{O}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*}\right]/\partial \tau =& M^{AO}(\phi^*)\partial\left[\left.\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*}\right]/\partial \tau \\ &+ \left.\frac{\partial M^{AO}(\phi^*)}{\partial \tau}\,\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*} \\ &+ \sum \left.\frac{\partial M^{zO}(\phi^*)}{\partial \tau}\,\frac{\partial ln\left(p^{zO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*}, \\ & z = B, N_1, \ldots, N_n. \end{aligned} \tag{B19}$$

Moreover,

$$\frac{\partial M^{AO}(\phi^*)}{\partial \tau} = (1-\sigma)\, M^{AO}(\phi^*) \left(1 - M^{AO}(\phi^*)\right) \left.\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*}, \tag{B20}$$

$$\frac{\partial M^{zO}(\phi^*)}{\partial \tau} = -\,(1-\sigma)\, M^{AO}(\phi^*) M^{zO}(\phi^*) \left.\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*}, z = B, N_1, \ldots, N_n. \tag{B21}$$

Notice that $\left.\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*} = \left.\frac{\partial ln\left(p^{zO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*}, z = B, N_1, \ldots, N_n$. Substitute equation (B20), (B21) into equation (B19) we have

$$\partial \left[ \left.\frac{\partial ln\left(p^{O}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*} \right] / \partial \tau = M^{AO}(\phi^*) \partial \left[ \left.\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*} \right] / \partial \tau. \tag{B22}$$

That is, $\partial \left[ \left.\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*} \right] / \partial \tau > \partial \left[ \left.\frac{\partial ln\left(p^{O}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*} \right] / \partial \tau > 0$. So $\frac{\partial \Omega}{\partial \tau}\big|_{\phi=\phi^*} > 0$, $\left.\frac{\partial \phi^*}{\partial \tau}\right|_{\phi=\phi^*} < 0$ holds true.

**Proof of Corollary 2.3:** By the implicit function theorem we have $\left.\frac{\partial \phi^*}{\partial \delta}\right|_{\phi=\phi^*} = -\left.\frac{\partial F}{\partial \delta} / \frac{\partial F}{\partial \phi}\right|_{\phi=\phi^*}$, $\left.\frac{\partial \phi^*}{\partial \delta'}\right|_{\phi=\phi^*} = \left.\frac{\partial F}{\partial \delta'} / \frac{\partial F}{\partial \phi}\right|_{\phi=\phi^*}$. Notice $\left.\frac{\partial F}{\partial \phi}\right|_{\phi=\phi^*} < 0$, $F = (1-\sigma)\,\Omega$ and $1-\sigma < 0$, to prove corollary 2.3 we must prove $\left.\frac{\partial \phi^*}{\partial \delta}\right|_{\phi=\phi^*} > 0 \iff \frac{\partial \Omega}{\partial \delta}\big|_{\phi=\phi^*} < 0$ and $\left.\frac{\partial \phi^*}{\partial \delta'}\right|_{\phi=\phi^*} > 0 \iff \frac{\partial \Omega}{\partial \delta'}\big|_{\phi=\phi^*} < 0$.

First we prove $\frac{\partial \Omega}{\partial \delta}\big|_{\phi=\phi^*} < 0$. When $\phi^* \in (0,1)$, compute the first-order derivative of $\left.\frac{\partial ln\left(p^{BO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*}$ with respect to $\delta$ as

$$\partial \left[ \left.\frac{\partial ln\left(p^{BO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*} \right] / \partial \delta = \frac{\phi^* e^{\delta \phi^*}}{\frac{e^{\delta\phi^*}-1}{\delta} + \frac{e^{\lambda}-e^{\lambda\phi^*}}{\lambda}} + \frac{\left(e^{\lambda\phi^*} - e^{\delta\phi^*}\right)\left(\frac{1+e^{\delta\phi^*}(\delta\phi^*-1)}{\delta^2}\right)}{\left[\frac{e^{\delta\phi^*}-1}{\delta} + \frac{e^{\lambda}-e^{\lambda\phi^*}}{\lambda}\right]^2} > 0. \tag{B23}$$

Combining with $\partial \left[ \left.\frac{\partial ln\left(p^{iO}(\phi)\right)}{\partial \phi}\right|_{\phi=\phi^*} \right] / \partial \delta = 0, i = A, N_1, \ldots, N_n$, compute the first-order derivative of $\frac{\partial ln\left(p^{O}(\phi)\right)}{\partial\phi}\Big|_{\phi=\phi^*}$ with respect to $\delta$ as

$$\partial\left[\frac{\partial ln\left(p^{O}(\phi)\right)}{\partial\phi}\Bigg|_{\phi=\phi^*}\right]/\partial\delta = M^{BO}(\phi^*)\partial\left[\frac{\partial ln\left(p^{BO}(\phi)\right)}{\partial\phi}\Bigg|_{\phi=\phi^*}\right]/\partial\delta. \tag{B24}$$

Hence $\partial\left[\frac{\partial ln\left(p^{AO}(\phi)\right)}{\partial\phi}\Big|_{\phi=\phi^*}\right]/\partial\delta = 0 < \partial\left[\frac{\partial ln\left(p^{O}(\phi)\right)}{\partial\phi}\Big|_{\phi=\phi^*}\right]/\partial\delta$, that is, $\frac{\partial\Omega}{\partial\delta}\big|_{\phi=\phi^*} < 0$, $\frac{\partial\phi^*}{\partial\delta}\Big|_{\phi=\phi^*} > 0$ is proved. Likewise, $\frac{\partial\Omega}{\partial\delta'}\big|_{\phi=\phi^*} < 0$ and $\frac{\partial\phi^*}{\partial\delta'}\Big|_{\phi=\phi^*} > 0$ can be proved.

## TFP estimation

Our data preparation for TFP estimation refers to Brandt et al. (2012) and Dai et al. (2016). We use the perpetual inventory method and the real depreciation rate in the ASIF dataset to calculate the true value of the capital stock. In order to accurately capture the price trends of firms, we employ the method of Smeets and Warzynski (2013) to construct firm-level price index by means of the firm-product-level trade information disclosed in CCTS and then deflate the output of exporters. As we do not hold the information of product prices of non-exporting firms, for those firms we construct the output deflation index based on the producer ex-factory price index issued by NBS. The input deflation index is constructed with the industry output deflation index and the 2002 industry Input-Output table. We employ the Brandt-Rawski index to deflate investments.

We draw on the semi-parametric method proposed by Ackerberg et al. (2015) for TFP estimation. We work with a logarithmic Cobb-Douglas production function:

$$Y_{it} = \beta_0 + \beta_L L_{it} + \beta_K K_{it} + w_{it} + \epsilon_{it}, \tag{B25}$$

where $Y_{it}$, $L_{it}$, $K_{it}$, and $w_{it}$ are respectively the log value added, log labor, log capital, and productivity of firm $i$ in year $t$.

Ackerberg et al. (2015) make assumptions on timing as follows. $K_{it}$ is choses at $t-1$, intermediate inputs are determined at $t$, and $L_{it}$ is chosen at $t-b$, $0 < b < 1$ due to labor market frictions (e.g, training time for employees). We use intermediate inputs as the proxy for unobserved productivity. And the firm's demand for intermediate inputs at $t$ depending on $L_{it}$ is:

$$M_{it} = m_t(w_{it}, K_{it}, L_{it}). \tag{B26}$$

$w_{it}$ derives from the inverted function of $M_{it}$ and the first stage specification yields as:

$$Y_{it} = \beta_K K_{it} + \beta_L L_{it} + m_t^{-1}(M_{it}, K_{it}, L_{it}) + \epsilon_{it}. \tag{B27}$$

We use third-order polynomials $\Phi(M_{it}, K_{it}, L_{it})$ to approximate $\beta_K K_{it} + \beta_L L_{it} + m_t^{-1}$, hence in the first step, $\Phi(M_{it}, K_{it}, L_{it})$ is estimated as the output net of $\epsilon_{it}$.

Assume that productivity evolves as a first order Markov process, $w_{it} = f(w_{i,t-1}) + \zeta_{it}$, hence $E(\zeta_{it}|K_{it}) = 0$ and $E(\zeta_{it}|L_{i,t-1}) = 0$ according to the timing assumptions. Starting with an initial guess for the parameters $\beta_K$ and $\beta_L$ with OLS regression, we obtain a preliminary estimate of $w_{it}$ and $w_{i,t-1}$ by the following specifications:

$$w_{it}(\beta_K, \beta_L) = \hat{\Phi}(M_{it}, K_{it}, L_{it}) - \beta_K K_{it} - \beta_L L_{it}, \tag{B28}$$

$$w_{i,t-1}(\beta_K, \beta_L) = \hat{\Phi}(M_{i,t-1}, K_{i,t-1}, L_{i,t-1}) - \beta_K K_{i,t-1} - \beta_L L_{i,t-1}. \tag{B29}$$

Hence in the second step, we regress $w_{it}(\beta_K, \beta_L)$ on $w_{i,t-1}(\beta_K, \beta_L)$ to obtain residuals $\hat{\zeta}_{it}(\beta_K, \beta_L)$. In the last step, we find the parameters $\hat{\beta}_K$ and $\hat{\beta}_L$ that set the following moment conditions to zero:

$$\frac{1}{T}\frac{1}{N}\sum_t \sum_i \hat{\zeta}_{it}(\beta_K, \beta_L) \begin{pmatrix} K_{it} \\ L_{i,t-1} \end{pmatrix} \tag{B30}$$

The estimates of TFP are finally calculated with $\hat{\beta}_K$ and $\hat{\beta}_L$. Considering the possible differences in the production functions between industries, we estimate TFP by 3-digit CIC industry. The estimates of TFP are winsorized at the 1st and 99th quantiles to eliminate outliers.

## Chinese industries under analysis

We investigate the following Chinese manufacturing industries with a 2-digit CIC code between 13 and 42: agricultural and sideline food processing (13); food manufacturing (14); beverage manufacturing (15); tobacco products manufacturing (16);

textiles (17); apparel, shoes and hat manufacturing (18); leather, fur, feather (velvet) and their products (19); wood processing and wood, bamboo, rattan, palm and grass products (20); furniture manufacturing (21); paper and paper products (22); printing and recording media reproduction (23); cultural, educational and sporting products manufacturing (24); petroleum processing, coking and nuclear fuel processing (25); chemical raw materials and chemical products manufacturing (26); pharmaceutical manufacturing (27); chemical fiber manufacturing (28); rubber products (29); plastic products (30); non-metallic mineral products (31); ferrous metal smelting and rolling processing (32); non-ferrous metal smelting and rolling processing (33); metal products (34); general equipment manufacturing (35); special equipment manufacturing (36); transportation equipment manufacturing (37); electrical machinery and equipment manufacturing (39); communication equipment, computer and other electronic equipment manufacturing (40); instrumentation, cultural and office machinery manufacturing (41); handicrafts and other manufacturing (42).

# Figures and tables

Table B1: Production coefficients and returns to scale, by industry

| 2-digit CIC Industry | Elasticities | | Returns to scale | |
|---|---|---|---|---|
| | Labor | Capital | Mean | Median |
| 13 | 1.261 | 0.151 | 1.411 | 1.307 |
| 14 | 0.608 | 0.535 | 1.143 | 1.124 |
| 15 | 0.021 | 0.817 | 0.838 | 0.777 |
| 16 | 0.896 | 0.881 | 1.777 | 1.800 |
| 17 | 0.625 | 0.456 | 1.082 | 1.047 |
| 18 | 1.220 | 0.208 | 1.428 | 1.497 |
| 19 | 1.413 | 0.123 | 1.536 | 1.498 |
| 20 | 0.760 | 0.286 | 1.046 | 0.794 |
| 21 | 1.471 | 0.173 | 1.644 | 1.514 |
| 22 | 0.619 | 0.437 | 1.057 | 1.580 |
| 23 | -0.258 | 0.989 | 0.731 | 0.722 |
| 24 | 1.043 | 0.289 | 1.332 | 1.375 |
| 25 | 0.389 | 0.567 | 0.956 | 0.939 |
| 26 | 0.240 | 0.697 | 0.937 | 0.858 |
| 27 | 0.744 | 0.586 | 1.331 | 1.334 |
| 28 | 0.051 | 0.662 | 0.714 | 0.572 |
| 29 | 1.231 | 0.185 | 1.416 | 1.424 |
| 30 | 1.103 | 0.368 | 1.471 | 1.503 |
| 31 | 0.568 | 0.402 | 0.970 | 0.958 |
| 32 | 0.741 | 0.489 | 1.230 | 1.274 |
| 33 | 0.964 | 0.296 | 1.261 | 1.670 |
| 34 | 1.213 | 0.352 | 1.565 | 1.465 |
| 35 | 0.983 | 0.357 | 1.340 | 1.209 |
| 36 | 0.703 | 0.398 | 1.102 | 0.901 |
| 37 | 1.315 | 0.338 | 1.654 | 1.669 |
| 39 | 1.384 | 0.229 | 1.613 | 1.645 |
| 40 | 1.116 | 0.372 | 1.488 | 1.415 |
| 41 | 1.341 | 0.183 | 1.524 | 1.698 |
| 42 | 0.592 | 0.337 | 0.929 | 0.739 |

*Notes:* The table reports the estimated output elasticities for the Cobb-Douglas production function. Columns 1-3 display the mean elasticities (by 3-digit industry) with respect to each production factor for all firms. Columns 4 and 5 display the mean and median returns to scale. The correspondence between industry codes and names is provided in the Appendix.

Table B2: Partial results of the property balancing tests of matching for groups T1 (switching from non-export) and C1

| | Length=7, year=2000<br>Before matching:<br>T=222, C=15503<br>After matching:<br>T=222, C=947 | | | Length=6, year=2001<br>Before matching:<br>T=46, C=23443<br>After matching:<br>T=46, C=230 | | | Length=5, year=2002<br>Before matching:<br>T=38, C=32492<br>After matching:<br>T=38, C=190 | | | Length=4, year=2003<br>Before matching:<br>T=182, C=48819<br>After matching:<br>T=181, C=860 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | %bias | t | p> \|t\| | %bias | t | p> \|t\| | %bias | t | p> \|t\| | %bias | t | p> \|t\| |
| Ln Asset | 0.5 | 0.05 | 0.96 | -4.2 | -0.2 | 0.839 | -4.4 | -0.4 | 0.689 | -4.4 | -0.4 | 0.689 |
| Age | 4.3 | 0.63 | 0.53 | 1.8 | 0.15 | 0.881 | 1.2 | 0.23 | 0.816 | 1.2 | 0.23 | 0.816 |
| Employee | 16.1 | 1.52 | 0.129 | 7.8 | 0.36 | 0.722 | 7.8 | 0.77 | 0.442 | 7.8 | 0.77 | 0.442 |
| Labor_Prod | -7.4 | -0.78 | 0.436 | -1 | -0.05 | 0.96 | -7 | -0.6 | 0.551 | -7 | -0.6 | 0.551 |
| Ave wage | 12.5 | 1.7 | 0.09 | 33.5 | 2.58 | 0.011 | 28.7 | 2.66 | 0.008 | 28.7 | 2.66 | 0.008 |
| Ln KL | -4.8 | -0.44 | 0.658 | -13.4 | -0.6 | 0.551 | -3.5 | -0.29 | 0.771 | -3.5 | -0.29 | 0.771 |
| Industry | 5.5 | 0.57 | 0.568 | 11.1 | 0.52 | 0.603 | -3.2 | -0.3 | 0.766 | -3.2 | -0.3 | 0.766 |
| HHI | 5.6 | 0.54 | 0.592 | -6.9 | -0.23 | 0.818 | -2.1 | -0.21 | 0.838 | -2.1 | -0.21 | 0.838 |
| Liquidity | 1.6 | 0.19 | 0.852 | 8 | 0.39 | 0.7 | -1.1 | -0.11 | 0.914 | -1.1 | -0.11 | 0.914 |

| | Length=3, year=2004<br>Before matching:<br>T=207, C=89204<br>After matching:<br>T=206, C=995 | | | Length=2, year=2005<br>Before matching:<br>T=109, C=109656<br>After matching:<br>T=108, C=523 | | | Length=1, year=2006<br>Before matching:<br>T=480, C=135468<br>After matching:<br>T=474, C=2217 | | |
|---|---|---|---|---|---|---|---|---|---|
| | %bias | t | p> \|t\| | %bias | t | p> \|t\| | %bias | t | p> \|t\| |
| Ln Asset | -4.4 | -0.42 | 0.675 | -18.2 | -1.23 | 0.221 | -8.2 | -1.16 | 0.247 |
| Age | 0.6 | 0.18 | 0.858 | -7.7 | -0.72 | 0.474 | -2.1 | -0.82 | 0.415 |
| Employee | -6.8 | -0.54 | 0.588 | 8.2 | 0.55 | 0.58 | -1.1 | -0.15 | 0.881 |
| Labor_Prod | -6.6 | -0.62 | 0.538 | -9.4 | -0.6 | 0.548 | -1.8 | -0.26 | 0.797 |
| Ave wage | 10 | 0.63 | 0.528 | -7.2 | -0.36 | 0.718 | 7 | 1.3 | 0.194 |
| Ln KL | -4.2 | -0.38 | 0.704 | 1.7 | 0.11 | 0.912 | -6.7 | -0.99 | 0.324 |
| Industry | -3.9 | -0.4 | 0.686 | -6.7 | -0.49 | 0.622 | -1 | -0.16 | 0.874 |
| HHI | -3.8 | -0.38 | 0.702 | 3.8 | 0.35 | 0.73 | 0 | 0.01 | 0.995 |
| Liquidity | 1.4 | 0.16 | 0.872 | -9.6 | -0.74 | 0.462 | -1.6 | -0.25 | 0.802 |

*Notes:* This table reports partial results of property balancing tests. We conducted more than one matchings for each group of treated firms besides the group of 7-year engagement, while we here report the test result of one match of each group for the sake of space. The matching years are reported in the heading of each column. The covariants used for calculating the propensity score include the firm's total assets (*LnAsset*), age (*Age*), employees (*Employee*), labor productivity (*Labor_Prod*), average wage (*Avewage*), capital intensity ($LnKL_{it}$), liquidity ($Liquidity_{it}$), industry Herfindahl index ($HHI$), and 4-digit industry classification code ($Industry$).

Table B3: Partial results of the property balancing tests of matching for groups T2 (switching from ordinary exports) and C2

| | Length=7, year=2000<br>Before matching:<br>T=43, C=629<br>After matching:<br>T=39, C=151 | | | Length=6, year=2001<br>Before matching:<br>T=25, C=332<br>After matching:<br>T=24, C=87 | | | Length=5, year=2002<br>Before matching:<br>T=31, C=662<br>After matching:<br>T=27, C=94 | | | Length=4, year=2003<br>Before matching:<br>T=51, C=1341<br>After matching:<br>T=51, C=206 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | %bias | t | p> \|t\| | %bias | t | p> \|t\| | %bias | t | p> \|t\| | %bias | t | p> \|t\| |
| Ln Asset | -1 | -0.05 | 0.962 | 11 | 0.38 | 0.702 | -4 | -0.16 | 0.877 | -19.5 | -0.93 | 0.356 |
| Age | 0.4 | 0.02 | 0.983 | 0.9 | 0.06 | 0.955 | -0.2 | -0.02 | 0.981 | -6.1 | -0.67 | 0.502 |
| Employee | 0.7 | 0.04 | 0.97 | 26.1 | 1.13 | 0.263 | -1.4 | -0.15 | 0.879 | -9.1 | -0.52 | 0.603 |
| Labor_P | -1.8 | -0.09 | 0.927 | -10.3 | -0.44 | 0.662 | 4.8 | 0.17 | 0.865 | -19.7 | -0.95 | 0.346 |
| Ave wage | 0.4 | 0.03 | 0.979 | -2.7 | -0.1 | 0.917 | -3.7 | -0.13 | 0.894 | -11.7 | -0.6 | 0.55 |
| Ln KL | -6.5 | -0.3 | 0.767 | -8.8 | -0.34 | 0.737 | 12.1 | 0.44 | 0.661 | -9.3 | -0.43 | 0.666 |
| Industry | 10.1 | 0.46 | 0.648 | 6.8 | 0.23 | 0.817 | 6.4 | 0.24 | 0.814 | 7.9 | 0.39 | 0.694 |
| HHI | 5.3 | 0.23 | 0.817 | 8 | 0.3 | 0.763 | -8.3 | -0.32 | 0.754 | -0.7 | -0.06 | 0.955 |
| Liquidity | -1.2 | -0.05 | 0.956 | 3.1 | 0.1 | 0.917 | 6.7 | 0.22 | 0.827 | 0.3 | 0.01 | 0.989 |

| | Length=3, year=2004<br>Before matching:<br>T=222, C=3901<br>After matching:<br>T=222, C=806 | | | Length=2, year=2005<br>Before matching:<br>T=72, C=4438<br>After matching:<br>T=66, C=289 | | | Length=1, year=2006<br>Before matching:<br>T=533, C=6311<br>After matching:<br>T=526, C=1678 | | |
|---|---|---|---|---|---|---|---|---|---|
| | %bias | t | p> \|t\| | %bias | t | p> \|t\| | %bias | t | p> \|t\| |
| Ln Asset | -3.7 | -0.36 | 0.716 | -17.7 | -0.96 | 0.338 | -9.5 | -1.45 | 0.149 |
| Age | -2.7 | -0.43 | 0.671 | -4.6 | -0.69 | 0.493 | -5.7 | -1.6 | 0.109 |
| Employee | -0.3 | -0.03 | 0.978 | -5.5 | -0.87 | 0.384 | -11.7 | -1.25 | 0.211 |
| Labor_P | 3.2 | 0.32 | 0.748 | -16.3 | -0.89 | 0.374 | -1.5 | -0.23 | 0.818 |
| Ave wage | 4 | 0.36 | 0.717 | -14.7 | -0.57 | 0.569 | -5.1 | -0.81 | 0.418 |
| Ln KL | -6 | -0.62 | 0.538 | -10.3 | -0.56 | 0.577 | -5.4 | -0.84 | 0.4 |
| Industry | 5.9 | 0.63 | 0.531 | -7.3 | -0.42 | 0.676 | -1.6 | -0.27 | 0.788 |
| HHI | 1.1 | 0.11 | 0.912 | -13.2 | -0.83 | 0.407 | -1.1 | -0.21 | 0.831 |
| Liquidity | 5.2 | 0.54 | 0.589 | 5.7 | 0.33 | 0.742 | 3.8 | 0.64 | 0.524 |

*Notes:* This table reports partial results of property balancing tests. We conducted more than one matchings for each group of treated firms besides the group of 7-year engagement, while we here report the test result of one match of each group for the sake of space. The matching years are reported in the heading of each column. The covariants used for calculating the propensity score include the firm's total assets (*LnAsset*), age (*Age*), employees (*Employee*), labor productivity (*Labor_Prod*), average wage (*Avewage*), capital intensity ($LnKL_{it}$), liquidity ($Liquidity_{it}$), industry Herfindahl index (*HHI*), and 4-digit industry classification code (*Industry*).

Table B4: Productivity and the engagement in processing trade, 1- to 7-year engagement

| | (1a) Ln TFP | (2a) Ln D_TFP$_{t=1}$ | (3a) Ln D_TFP$_{t=2}$ | (4a) Ln D_TFP$_{t=3}$ | (5a) Ln D_TFP$_{t=4}$ | (6a) Ln D_TFP$_{t=5}$ | (7a) Ln D_TFP$_{t=6}$ | (8a) Ln D_TFP$_{t=7}$ |
|---|---|---|---|---|---|---|---|---|
| *Panel A: Sample of treatment group T1 and matched C1* | | | | | | | | |
| After | 0.135*** | | | | | | | |
| | (0.020) | | | | | | | |
| Treated | | 0.100** | 0.074 | 0.202** | -0.014 | 0.288** | 0.115 | 0.118 |
| | | (0.040) | (0.061) | (0.079) | (0.117) | (0.140) | (0.147) | (0.165) |
| Control variables | Y | Y | Y | Y | Y | Y | Y | Y |
| Year and industry FE | Y | Y | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | N | N | N | N | N | N | N |
| Province FE | N | Y | Y | Y | Y | Y | Y | Y |
| Observations | 35330 | 7560 | 4734 | 3932 | 2561 | 1591 | 1352 | 1061 |
| $R^2$ | 0.927 | 0.190 | 0.240 | 0.309 | 0.362 | 0.473 | 0.479 | 0.498 |
| | (1b) Ln TFP | (2b) Ln D_TFP$_{t=1}$ | (3b) Ln D_TFP$_{t=2}$ | (4b) Ln D_TFP$_{t=3}$ | (5b) Ln D_TFP$_{t=4}$ | (6b) Ln D_TFP$_{t=5}$ | (7b) Ln D_TFP$_{t=6}$ | (8b) Ln D_TFP$_{t=7}$ |
| *Panel B: Sample of treatment group T2 and matched C2* | | | | | | | | |
| After | 0.052** | | | | | | | |
| | (0.024) | | | | | | | |
| Treated | | 0.062* | 0.168** | 0.152** | 0.106 | -0.022 | 0.142 | 0.169 |
| | | (0.034) | (0.068) | (0.076) | (0.163) | (0.217) | (0.337) | (0.497) |
| Control variables | Y | Y | Y | Y | Y | Y | Y | Y |
| Year and industry FE | Y | Y | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | N | N | N | N | N | N | N |
| Province FE | N | Y | Y | Y | Y | Y | Y | Y |
| Observations | 16295 | 4427 | 2100 | 1602 | 539 | 303 | 192 | 101 |
| $R^2$ | 0.955 | 0.180 | 0.263 | 0.336 | 0.578 | 0.646 | 0.628 | 0.778 |

*Notes:* Dependent variables are TFP estimated by following Ackerberg et al. (2015). In all regressions, we control for log firm age, size, average wage, the capital intensity, subsidy, liquidity, and industry concentration. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at firm level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B5: Product varieties, product quality, and the engagement in processing trade, 1- to 7-year engagement

| | (1a) Ln Variety | (2a) Ln D_Variety$_{t=1}$ | (3a) Ln D_Variety$_{t=2}$ | (4a) Ln D_Variety$_{t=3}$ | (5a) Ln D_Variety$_{t=4}$ | (6a) Ln D_Variety$_{t=5}$ | (7a) Ln D_Variety$_{t=6}$ | (8a) Ln D_Variety$_{t=7}$ |
|---|---|---|---|---|---|---|---|---|
| *Panel A* | | | | | | | | |
| After | 0.166*** | | | | | | | |
| | (0.025) | | | | | | | |
| Treated | | 0.143*** | 0.097* | 0.187*** | 0.332*** | 0.327* | 0.110 | 0.047 |
| | | (0.027) | (0.051) | (0.066) | (0.120) | (0.168) | (0.277) | (0.339) |
| Control variables | Y | Y | Y | Y | Y | Y | Y | Y |
| Year and industry FE | Y | Y | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | N | N | N | N | N | N | N |
| Province FE | N | Y | Y | Y | Y | Y | Y | Y |
| Observations | 16201 | 4394 | 2082 | 1587 | 537 | 303 | 191 | 101 |
| $R^2$ | 0.818 | 0.165 | 0.223 | 0.268 | 0.406 | 0.462 | 0.558 | 0.757 |
| | (1b) Ln Quality | (2b) Ln D_Quality$_{t=1}$ | (3b) Ln D_Quality$_{t=2}$ | (4b) Ln D_Quality$_{t=3}$ | (5b) Ln D_Quality$_{t=4}$ | (6b) Ln D_Quality$_{t=5}$ | (7b) Ln D_Quality$_{t=6}$ | 7b) Ln D_Quality$_{t=7}$ |
| *Panel B* | | | | | | | | |
| After | 0.101 | | | | | | | |
| | (0.131) | | | | | | | |
| Treated | | 0.320** | -0.008 | -0.466 | -0.452 | -0.667 | -0.580 | 0.673 |
| | | (0.147) | (0.229) | (0.336) | (0.448) | (0.755) | (0.764) | (1.383) |
| Control variables | Y | Y | Y | Y | Y | Y | Y | Y |
| Year and industry FE | Y | Y | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | N | N | N | N | N | N | N |
| Province FE | N | Y | Y | Y | Y | Y | Y | Y |
| Observations | 14768 | 3870 | 1826 | 1388 | 457 | 269 | 167 | 92 |
| $R^2$ | 0.771 | 0.147 | 0.209 | 0.283 | 0.370 | 0.479 | 0.569 | 0.690 |

*Notes:* Dependent variables are the indicators for the firm's performance of ordinary exports. In all regressions, we control for log firm age, productivity, size, the quality of ordinary products, average wage, the capital intensity, subsidy, liquidity, and industry concentration, log product quality, and log product varieties. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at firm level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B6: Overseas markets, export revenue, and the engagement in processing trade, 1- to 7-year engagement

| | (1a) Ln Market | (2a) Ln D_Market$_{t=1}$ | (3a) Ln D_Market$_{t=2}$ | (4a) Ln D_Market$_{t=3}$ | (5a) Ln D_Market$_{t=4}$ | (6a) Ln D_Market$_{t=5}$ | (7a) Ln D_Market$_{t=6}$ | (8a) Ln D_Market$_{t=7}$ |
|---|---|---|---|---|---|---|---|---|
| *Panel A* | | | | | | | | |
| After | 0.065*** | | | | | | | |
| | (0.021) | | | | | | | |
| Treated | | 0.049* | 0.018 | 0.042 | 0.100 | 0.486** | 0.330 | 0.381 |
| | | (0.025) | (0.047) | (0.062) | (0.123) | (0.197) | (0.254) | (0.371) |
| Control variables | Y | Y | Y | Y | Y | Y | Y | Y |
| Year and industry FE | Y | Y | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | N | N | N | N | N | N | N |
| Province FE | N | Y | Y | Y | Y | Y | Y | Y |
| Observations | 14768 | 4064 | 1953 | 1493 | 499 | 287 | 178 | 97 |
| $R^2$ | 0.899 | 0.191 | 0.260 | 0.331 | 0.468 | 0.534 | 0.626 | 0.843 |
| | (1b) Ln OrdExp | (2b) Ln D_OrdExp$_{t=1}$ | (3b) Ln D_OrdExp$_{t=2}$ | (4b) Ln D_OrdExp$_{t=3}$ | (5b) Ln D_OrdExp$_{t=4}$ | (6b) Ln D_OrdExp$_{t=5}$ | (7b) Ln D_OrdExp$_{t=6}$ | 7b) Ln D_OrdExp$_{t=7}$ |
| *Panel B* | | | | | | | | |
| After | 0.103** | | | | | | | |
| | (0.050) | | | | | | | |
| Treated | | 0.130** | -0.154 | -0.109 | 0.487** | 0.577 | 1.189** | 1.197* |
| | | (0.057) | (0.102) | (0.141) | (0.229) | (0.383) | (0.557) | (0.703) |
| Control variables | Y | Y | Y | Y | Y | Y | Y | Y |
| Year and industry FE | Y | Y | Y | Y | Y | Y | Y | Y |
| Firm FE | Y | N | N | N | N | N | N | N |
| Province FE | N | Y | Y | Y | Y | Y | Y | Y |
| Observations | 14767 | 4064 | 1951 | 1493 | 499 | 287 | 178 | 97 |
| $R^2$ | 0.822 | 0.197 | 0.272 | 0.317 | 0.488 | 0.558 | 0.545 | 0.761 |

*Notes:* Dependent variables are the indicators for the firm's performance of ordinary exports. In all regressions, we control for log firm age, productivity, size, the quality of ordinary products, average wage, the capital intensity, subsidy, liquidity, and industry concentration, log product quality, and log product varieties. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at firm level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

## Table B7: Lead values of spillovers and the performance of domestic non-processing firms

| | Non-exporters | Ordinary Exporters | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Dep.Var | ***Δ***Ln TFP | ***Δ***Ln TFP | ***Δ***Ln Variety | ***Δ***Ln Quality | ***Δ***Ln Market | ***Δ***Ln OrdExp |
| ***Δ***Lead Horizontal | 0.052 | 0.143 | 0.440 | 0.276 | -0.126 | 0.709 |
| | (0.140) | (0.434) | (0.383) | (1.807) | (0.336) | (0.623) |
| ***Δ***Lead Horizontal×Trend | -0.004 | -0.045 | -0.217* | 0.703 | 0.050 | -0.098 |
| | (0.056) | (0.139) | (0.119) | (0.693) | (0.107) | (0.244) |
| ***Δ***Lead Backward | -0.663 | -0.976 | -0.623 | -16.374 | -0.052 | -0.646 |
| | (0.806) | (2.852) | (2.591) | (14.152) | (1.944) | (6.765) |
| ***Δ***Lead Backward×Trend | -0.138 | 1.285 | 0.726 | 7.569 | 0.464 | 1.229 |
| | (0.409) | (0.970) | (0.877) | (5.569) | (0.735) | (2.000) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y | Y | Y |
| Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 239844 | 14051 | 11085 | 9519 | 9519 | 9519 |
| $R^2$ | 0.101 | 0.122 | 0.050 | 0.052 | 0.251 | 0.183 |

*Notes:* Dependent variables given in each column heading are the difference in the firm's outcomes. In all regressions, we control for industry concentration, industry markup, the firm's market share, age, size, average wage, capital intensity, subsidy, and liquidity. In columns (3)-(6), we further control for productivity; in columns (5) and (6), log product varieties and log product quality are also controlled. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at 4-digit industry level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

## Table B8: Spillovers on domestic non-processing firms, no interactions

| | Non-exporters | Ordinary Exporters | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Dep.Var | ***Δ***Ln TFP | ***Δ***Ln TFP | ***Δ***Ln Variety | ***Δ***Ln Quality | ***Δ***Ln Market | ***Δ***Ln OrdExp |
| ***Δ***Horizontal | -0.063 | 0.322** | 0.150 | 0.114 | 0.020 | -0.003 |
| | (0.096) | (0.147) | (0.146) | (1.036) | (0.120) | (0.296) |
| ***Δ***Backward | -0.849** | -0.444 | 0.577 | 4.385 | 0.291 | 0.107 |
| | (0.380) | (0.722) | (0.779) | (4.162) | (0.628) | (1.938) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y | Y | Y |
| Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 325804 | 20981 | 16805 | 14513 | 14513 | 14513 |
| $R^2$ | 0.107 | 0.120 | 0.034 | 0.033 | 0.225 | 0.168 |

*Notes:* Dependent variables given in each column heading are the difference in the firm's outcomes. In all regressions, we control for industry concentration, industry markup, the firm's market share, age, size, average wage, capital intensity, subsidy, and liquidity. In columns (3)-(6), we further control for productivity; in columns (5) and (6), log product varieties and log product quality are also controlled. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at 4-digit industry level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B9: Spillovers on domestic non-processing firms, no control variables

| | Non-exporters | Ordinary Exporters | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Dep.Var | **$\Delta$**Ln TFP | **$\Delta$**Ln TFP | **$\Delta$**Ln Variety | **$\Delta$**Ln Quality | **$\Delta$**Ln Market | **$\Delta$**Ln OrdExp |
| **$\Delta$**Horizontal | 0.050 | 0.848** | -0.175 | -1.195 | -0.350 | -1.118* |
| | (0.143) | (0.366) | (0.345) | (2.111) | (0.270) | (0.592) |
| **$\Delta$**Horizontal×Trend | -0.028 | -0.195** | 0.072 | 0.281 | 0.119 | 0.416** |
| | (0.040) | (0.097) | (0.098) | (0.612) | (0.078) | (0.173) |
| **$\Delta$**Backward | -2.302** | -1.090 | 0.116 | -0.542 | -3.551 | -5.615 |
| | (1.080) | (1.869) | (1.627) | (9.657) | (2.199) | (4.438) |
| **$\Delta$**Backward×Trend | 0.565* | 0.329 | 0.101 | 0.346 | 1.309** | 1.891 |
| | (0.289) | (0.470) | (0.413) | (2.724) | (0.607) | (1.225) |
| Control variables | N | N | N | N | N | N |
| Year FE | Y | Y | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y | Y | Y |
| Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 461448 | 28760 | 23076 | 19787 | 23076 | 23076 |
| $R^2$ | 0.026 | 0.035 | 0.020 | 0.026 | 0.030 | 0.033 |

*Notes:* Dependent variables given in each column heading are the difference in the firm's outcomes. Robust standard errors clustered at 4-digit industry level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B10: Spillovers on domestic non-processing firms, interacting with year dummies

| | Non-exporters | Ordinary Exporters | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Dep.Var | **Δ**Ln TFP | **Δ**Ln TFP | **Δ**Ln Variety | **Δ**Ln Quality | **Δ**Ln Market | **Δ**Ln OrdExp |
| **Δ**Horizontal | 0.062 | 1.067** | 0.294 | 3.502 | 0.304 | -1.562 |
| | (0.121) | (0.477) | (0.561) | (2.944) | (0.554) | (1.059) |
| $Year_{2003}$ × **Δ**Horizontal | -0.213 | -0.023 | -0.497 | -4.922 | -0.500 | 0.371 |
| | (0.268) | (0.937) | (0.777) | (4.981) | (0.717) | (1.510) |
| $Year_{2004}$ × **Δ**Horizontal | 0.109 | -0.916 | -0.720 | -8.146** | -0.754 | 1.048 |
| | (0.483) | (0.744) | (0.661) | (3.870) | (0.582) | (1.233) |
| $Year_{2005}$ × **Δ**Horizontal | -0.101 | -0.827 | -0.184 | -1.876 | -0.252 | 0.428 |
| | (0.169) | (0.593) | (0.639) | (3.221) | (0.585) | (1.203) |
| $Year_{2006}$ × **Δ**Horizontal | -0.215 | -0.870 | 0.090 | -5.170 | -0.488 | 1.217 |
| | (0.261) | (0.583) | (0.746) | (4.479) | (0.634) | (1.241) |
| $Year_{2007}$ × **Δ**Horizontal | -0.260 | -0.956* | 0.100 | -1.395 | 0.044 | 3.830*** |
| | (0.218) | (0.504) | (0.639) | (3.455) | (0.593) | (1.148) |
| **Δ**Backward | -2.483*** | 4.179 | 0.239 | 11.638 | -5.437 | -2.426 |
| | (0.929) | (3.260) | (3.258) | (16.523) | (3.970) | (6.096) |
| $Year_{2003}$ × **Δ**Backward | 0.702 | -4.991 | 0.374 | -28.676 | 4.499 | -5.724 |
| | (1.639) | (4.119) | (4.037) | (21.077) | (3.993) | (9.190) |
| $Year_{2004}$ × **Δ**Backward | -4.150 | -10.046* | 1.976 | 8.324 | 4.159 | -4.151 |
| | (2.722) | (5.450) | (4.385) | (21.658) | (4.446) | (8.355) |
| $Year_{2005}$ × **Δ**Backward | 2.603*** | -4.898 | -0.657 | -19.664 | 7.048* | 5.772 |
| | (0.940) | (3.426) | (3.330) | (17.716) | (4.023) | (6.435) |
| $Year_{2006}$ × **Δ**Backward | 1.530 | -1.694 | 2.499 | 7.092 | 9.039** | 6.768 |
| | (1.617) | (4.054) | (4.260) | (26.120) | (4.390) | (8.482) |
| $Year_{2007}$ × **Δ**Backward | 3.218** | -4.993 | -0.472 | -3.862 | 4.120 | 1.291 |
| | (1.417) | (3.508) | (3.449) | (17.886) | (4.467) | (7.343) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y | Y | Y |
| Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 325804 | 20981 | 16805 | 14513 | 14513 | 14513 |
| $R^2$ | 0.107 | 0.121 | 0.034 | 0.034 | 0.225 | 0.170 |

*Notes:* Dependent variables given in each column heading are the difference in the firm's outcomes. In all regressions, we control for industry concentration, industry markup, the firm's market share, age, size, average wage, capital intensity, subsidy, and liquidity. In columns (3)-(6), we further control for productivity; in columns (5) and (6), log product varieties and log product quality are also controlled. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at 4-digit industry level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B11: R&D engagement and inter-firm spillovers, no interactions

| | Non-exporters | Ordinary Exporters | | | | |
|---|---|---|---|---|---|---|
| Dep.Var | (1)<br>$\Delta$Ln TFP | (2)<br>$\Delta$Ln TFP | (3)<br>$\Delta$Ln Variety | (4)<br>$\Delta$Ln Quality | (5)<br>$\Delta$Ln Market | (6)<br>$\Delta$Ln OrdExp |
| RD | 0.002** | 0.003 | 0.002 | 0.055 | 0.014*** | 0.030** |
| | (0.001) | (0.007) | (0.003) | (0.042) | (0.004) | (0.014) |
| $\Delta$Horizontal | -0.098 | 0.188 | 0.249 | 0.970 | 0.115 | 0.271 |
| | (0.077) | (0.142) | (0.165) | (1.202) | (0.123) | (0.320) |
| $\Delta$Backward | 0.309 | -0.522 | -0.103 | 3.686 | 0.632 | 1.608 |
| | (0.296) | (0.656) | (0.839) | (5.023) | (0.759) | (2.073) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y | Y | Y |
| Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 219894 | 16056 | 13143 | 11405 | 11405 | 11405 |
| $R^2$ | 0.131 | 0.146 | 0.038 | 0.042 | 0.218 | 0.171 |

*Notes:* Dependent variables given in each column heading are the difference in the firm's outcomes. In all regressions, we control for industry concentration, industry markup, the firm's market share, age, size, average wage, capital intensity, subsidy, and liquidity. In columns (3)-(6), we further control for productivity; in columns (5) and (6), log product varieties and log product quality are also introduced. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at 4-digit industry level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table B12: New product innovation and inter-firm spillovers, no interactions

| | Non-exporters | Ordinary Exporters | | | | |
|---|---|---|---|---|---|---|
| Dep.Var | (1)<br>$\Delta$Ln TFP | (2)<br>$\Delta$Ln TFP | (3)<br>$\Delta$Ln Variety | (4)<br>$\Delta$Ln Quality | (5)<br>$\Delta$Ln Market | (6)<br>$\Delta$Ln OrdExp |
| NEW | 0.000 | 0.000 | -0.000 | 0.002 | -0.000 | -0.001 |
| | (0.000) | (0.000) | (0.000) | (0.002) | (0.000) | (0.001) |
| $\Delta$Horizontal | -0.062 | 0.321** | 0.145 | 0.114 | 0.021 | -0.005 |
| | (0.096) | (0.147) | (0.146) | (1.037) | (0.120) | (0.296) |
| $\Delta$Backward | -0.850** | -0.444 | 0.597 | 4.371 | 0.288 | 0.132 |
| | (0.380) | (0.722) | (0.780) | (4.161) | (0.628) | (1.944) |
| Control variables | Y | Y | Y | Y | Y | Y |
| Year FE | Y | Y | Y | Y | Y | Y |
| Industry FE | Y | Y | Y | Y | Y | Y |
| Province FE | Y | Y | Y | Y | Y | Y |
| Observations | 325788 | 20979 | 16804 | 14511 | 14511 | 14511 |
| $R^2$ | 0.107 | 0.120 | 0.034 | 0.033 | 0.225 | 0.168 |

*Notes:* Dependent variables given in each column heading are the difference in the firm's outcomes. In all regressions, we control for industry concentration, industry markup, the firm's market share, age, size, average wage, capital intensity, subsidy, and liquidity. In columns (3)-(6), we further control for productivity; in columns (5) and (6), log product varieties and log product quality are also introduced. Industry fixed effect is at the 4-digit level. Robust standard errors clustered at 4-digit industry level are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

# 3

# Vertical foreclosure and R&D alliance

## 3.1 Introduction

The survival of the fittest of firms has accelerated drastically with rapid technological changes, while the development of new technologies and products is under pressure from exorbitant innovation costs and uncertain prospects. Research and development (R&D) alliances have therefore become an increasingly common way to encourage strategic cooperation (Stuart, 1998; Sampson, 2007; Phelps, 2010; Lahiri and Narayanan, 2013). Such alliances are established to supplement firms with valuable resources that are available from alliance partners (Ireland et al., 2002; Rothaermel and Deeds, 2004; Sampson, 2007; Li et al., 2008), and on this basis, to promote the innovation of firms (Nieto and Santamaría, 2007; Lahiri and Narayanan, 2013). The transfer and exchange of knowledge within alliances essentially serve as intangible asset bonuses for partners. R&D alliances are therefore expected to play a role in areas where technology compensations can make up for insufficient financial incentives. For example, foreclosure is potentially preventable by licensing the technology to alliance partners that control for the bottleneck components in the vertical structure, given imperfect rent extraction.

Vertical foreclosure is extensively studied in theoretical frameworks (Salop and Scheffman, 1987; Hart et al., 1990; Choi and Yi, 2000; Rey and Tirole, 2007; Normann, 2011), and plenty of empirical evidence also demonstrates its prevalence in the industry (Waterman and Weiss, 1996; Chipty, 2001; Hastings and Gilbert, 2005; Suzuki, 2009; Hortaçsu and Syverson, 2007; Crawford et al., 2018). Foreclosures induced by vertical integration in industries subject to stringent scrutiny by authorities are paid more attention, such as cement and concrete, cable TV programming and distribution, and oil refining and distribution (Lafontaine and Slade, 2007). For instance, the acquisition of Unocal's West Coast refining and marketing assets by Tosco Corporation in 1997 is correlated to the increased wholesale gasoline prices (Hastings and Gilbert, 2005), and the integration between regional sports networks and program distributors in the US has also lead to vertical foreclosure aiming to raise the rival's cost (Crawford et al., 2018). Evidence from cross-sectional studies is present as well. Boehm and Sonntag (2020) propose that the international buyer-seller relationships between large US and foreign firms in a wide range of industries, including computer and electronics manufacturing, and financial services, etc., are more prone to break when the suppliers integrate with one of the buyer's competitors than integrating with non-competitors. The results imply that the distorting effects of vertical foreclosure on market competition has already spread through the global production network.

This paper thence explores the role of an R&D alliance in mitigating vertical foreclosure. We consider a model in which a vertically integrated upstream monopolist $A$ supplies input to its downstream affiliate and an independent downstream incumbent $S$, and the downstream market currently undergoes a wave of product innovation. Incumbents face a financially constrained innovative downstream entrant $W$ that has the potential for an upstream entry given a successful product innovation. Firms have different probabilities of failing to develop the new generation homogeneous product, in which case they face zero demand and withdraw from the market.[1] The input is a necessity in product innovation. The financial constraints of $W$, however, disable firm $A$'s upfront rent extraction, and $W$'s opportunistic upstream entry under an incomplete supply contract further sabotages the extraction, which may result in a refusal of input supply for $W$.[2] In light of this, firm $W$ has the option to license technology to $A$ under an R&D alliance improving $A$'s survival prospect, so as to make up for the insufficient rent extraction.

We therefore examine the possibility of easing foreclosure by technology licensing when any enforceable financial incentives are unavailable. We suggest that the R&D alliance plays a significant yet limited role in mitigating vertical foreclosure: the alliance mitigates vertical foreclosure when the cost advantage of firm $A$ is below a threshold which is an increasing function of the survival probability of the alliance partners. The rationale for the results comes from the trade-off between the upstream and downstream profits. In the case of a modest efficiency advantage of firm $A$, the market entry generates a significant rise in the downstream output and a considerable increment in the upstream profit for firm $A$. Although the downstream profit of firm $A$ decreases under intensified competition, the R&D alliance makes $A$ more likely to obtain this payoff. The augmented upstream profit and a better prospect in the downstream market outweigh the downstream loss and strengthen the willingness of firm $A$ to accommodate market entry. However, a larger efficiency advantage of firm $A$ places the independent downstream firms at a greater efficiency disadvantage, and reduces firm $A$'s upstream gain from a market entry. In this case, the downstream loss outweighs the upstream gain and reinforces firm $A$'s incentive for vertical foreclosure, which prevents firm $W$ from attempting to enter through the alliance.

We further discuss two variants of the benchmark model. We first take into

[1] The assumption of product update in this paper is made on the demand-side. Production-side progress, such as cost reductions, can lead to the same consequences.

[2] Chip is an example of the input of this kind. Chip plays a central role in many technological products and the cutting off of chip supply will cause a devastating blow to related firms.

account backward spillovers occurring in the supply chain between firms $A$ and $S$. Backward spillovers mean that suppliers can learn in the process of supplying technologically advanced downstream firms and improve on quality, production know-how, or make proficiency gains. Therefore, firm $A$ is assumed to improve its understanding of the product update and survival probability by absorbing the spillovers at a cost that is increasing in its new survival probability. A low unit absorptive cost encourages firm $A$ to appropriate spillovers, and a high cost otherwise discourages. We put forward the conditions for the R&D alliance to facilitate market entry in different subintervals of the unit absorptive cost.

Besides, market entry in a situation of multi-market linkage is discussed, where the two independent downstream firms can sell not only in the market in which they compete with the vertically integrated upstream monopolist but also in another market. Therefore, market entry affects the layout of firms in all markets and the profits of firm $A$ in particularly one tier of the vertical structure through multi-market linkage. We find that vertical foreclosure is relieved to some extent due to firm $A$'s additional upstream gains from the linkage, and the R&D alliance plays a better role in mitigating vertical foreclosure compared to the case of single downstream market.

This paper unfolds as follows. Section 3.2 reviews the related literature. Section 3.3 presents the benchmark model and examines the effects of an R&D alliance on eliminating vertical foreclosure. Section 3.4 discusses two variants of the benchmark model, including models that respectively incorporate backward spillovers and multi-market linkage. Section 3.5 concludes.

## 3.2 Related literature

This paper is related to three different literatures. The first is the literature on motivations of vertical foreclosure. Ordover et al. (1990) put forward the rationale of “raise the rival's costs” behind vertically integrated firms' foreclosure on the non-integrated downstream firms. While this argument has been criticized by the commitment concerns proposed in Hart et al. (1990) and Reiffen (1992). The two papers suggest that the rationale of “raise the rival's costs” depends on the credible commitment of the upstream supplier on not supplying the non-integrated downstream firm. Without an enforceable exclusive-deal contract, the vertically integrated firm will behave the same as if without a vertical merge. Ownership structure (Levy et al., 2018), input specifications (Choi and Yi, 2000), and varying efficiency of downstream targets (Reisinger and Tarantino, 2015), etc., are further discussed within the framework.[3]

The classic static literature on foreclosure has identified an array of mechanisms that render such a strategy profitable. The motivation of vertical foreclosure from a dynamic perspective has also been studied. Fumagalli and Motta (2020) argue that when the vertically integrated monopolist faces a more efficient downstream entrant in the current period and a more efficient upstream entrant in the next period, the monopolist will foreclose the current downstream entrant so as to discourage the upstream entry in the next period. Even if the upstream entry cannot be discouraged, the monopolist can also weaken future upstream competition by preventing the current downstream entry and thus extract profit from the more efficient upstream entrant.

We also examine vertical foreclosure in a dynamic situation where the downstream entrant is entitled to a potential upstream entry, which exacerbates incomplete rent extraction. Yet we consider product update where the vertically integrated upstream monopolist has an uncertain survival prospect in the downstream market, and present the conditions under which an R&D alliance can facilitate market entry with technology licensing. We thus contribute to the literature by providing an additional countermeasure of vertical foreclosure.

This paper is also linked to the literature on R&D alliances. The gradual flourish of R&D alliances spawns intense discussions. R&D alliances are believed to boost firms' innovation results via extensive internal technology utilization (Nieto and Santamaría, 2007; Lahiri and Narayanan, 2013), while the conflicts between reducing unintended knowledge leakage and maintaining continuous knowledge exchange inside alliances are great concerns and have received close attention (Kale et al., 2000; Robinson and Stuart, 2006; Sampson, 2007; Li et al., 2008).

A limited volume of papers relates R&D alliances to vertical foreclosure, however. Mathews (2006) studies strategic alliance and entry deterrence. He considers a strategic alliance between an entrenched incumbent and a small entrepreneurial firm and the two firms operate in different markets. Technology transfer inside the alliance makes the incumbent a potential competitor in one of the entrepreneurial firm's markets, while an equity deal can soften the entry incentives of the incumbent. This paper differs from Mathews (2006) in the following aspects. In contrast to the horizontal structure studied by Mathews (2006), we focus on a vertical

[3] A sample of papers in this field includes Ordover et al. (1992); Bolton and Whinston (1993); O'Brien and Shaffer (1992); McAfee and Schwartz (1994); Rey and Tirole (2007), and Jullien et al. (2014).

structure and thereby vertical foreclosure. Besides, Mathews (2006) focuses on the effect of equity sales on deterring market entry, yet we investigate under which conditions an R&D alliance not involving equity arrangements but referring to technology licensing can promote market entry.

In addition, this paper relates to the growing literature that studies backward spillovers in the supply chain. Ishii (2004) suggests that R&D externalities in vertical structures are common. An upstream supplier can develop its product better and provide superior services to the downstream partner if the supplier is fully aware of its partner's needs. Vertical spillovers hence play a role in the cooperative R&D between upstream and downstream firms. In the empirical studies, backward spillovers of inward FDI are some of those that have received the most attention. Javorcik (2004), Blalock and Gertler (2008), and Havranek and Irsova (2011) indicate that local suppliers with growing downstream FDI can achieve performance improvements via spillovers in the supply relationships. Based on the literature, this paper takes into account backward spillovers in the analytical framework of vertical foreclosure and studies how they interfere with market entry.

## 3.3 The benchmark model

The model consists of two incumbents, a vertically integrated upstream monopolist $A$ and an independent downstream firm $S$, and an innovative downstream entrant $W$ that has financial constraints. Firm $A$ is composed of an upstream affiliate $U_A$ and a downstream affiliate $D_A$, and maximizes the joint profit of its affiliates in the vertical structure, implying $U_A$ supplying $D_A$ at a price equal to its marginal cost. For the sake of concision, $U_A$ and $D_A$ are collectively referred to as firm $A$ hereafter.

The downstream market is assumed to encounter a wave of revolutionary product update, only firms that successfully develop a new generation homogeneous product can survive. Assuming that firm $S$ as a mighty firm can undoubtedly achieve innovation and survive, while firm $A$ can accomplish the innovation task with only a probability of $h_A < 1$. As an innovative startup, the probability of firm $W$ successfully developing the new product is $h$ and $h > h_A$. Although, as downstream firms, firms $S$ and $W$ can both enter the upstream market at zero cost: firm $S$ can flexibly set up its upstream production, while firm $W$ can only engage in producing input if it successfully innovates the new product. In other words, the independent downstream firms are entitled to an upstream entry only if they have a definite market prospect (i.e., will surely complete or have completed the product update).[4] Yet firms are differentiated on efficiency in the vertical structure: firm $A$ is at an advantage of zero marginal cost in upstream production over firms $S$ and $W$ that both have a marginal cost of $c$, $c \in \left(0, \frac{1}{2}\right]$; all firms have zero marginal cost in downstream production.[5]

Given the entrant's potential upstream entry, firm $A$'s privilege in vertical foreclosure is established by the assumption that the product development necessitates a very small amount of input.[6] That is, firm $A$ either supplies firm $W$ for its product innovation, or refuses to provide input supply, which deprives $W$'s chance of innovation and possible follow-up market entries. The uncertainties of firms' product development therefore impact firm $A$'s incentive toward foreclosure. Nevertheless, firm $A$ is assumed to be unable to charge firm $W$ anything before $W$ survives in the product contest, as firm $W$ has severe financial constraints, for example, lacking external investments due to its undetermined prospect of product development. Nor can firm $A$ postpone the charge by fixing a supply contract upfront for $W$'s post-innovation production, taking into account opportunistic behaviors that often arise in incomplete contracts that are prevalent in practice (Al-Najjar, 1995; Maskin and Tirole, 1999; Frydlinger and Hart, 2019; Hart, 2017), which makes the supply contract between $A$ and $W$ non-binding across phases. Namely, firm $W$ cannot commit to sourcing from $A$ under this contract but can instead opportunistically switch to self-production in the post-innovation phase. Financial constraints of the entrant and the incomplete contract result in the imperfect extraction capacity of firm $A$ which may motivate vertical foreclosure.

To get input for innovation, firm $W$ has the option of inviting firm $A$ into an R&D alliance where $W$ licenses its technology to $A$ and helps $A$ survive in the downstream market with a higher probability of $h$. We therefore aim to examine the possibility of easing foreclosure by compensating firm $A$ with technology licensing when no other enforceable financial incentives are available. A linear supply contract for $W$ is thereby considered.

The downstream market is characterized by a downward sloping inverse demand function $P(Q) = 1 - Q$ and $Q$ is the total industry output. Surviving downstream firms will compete on quantity. The configuration of active firms in

[4] The model assumes zero fixed costs of any market entry for the sake of simplification.

[5] Firms are thereby ensured non-negative profits from markets.

[6] For example, this input can be a target material used in the development of cutting-edge coating technology. In the experimental stage, researchers often only need the targets of a very small amount for experiments compared to the larger scale of input used in the commercialized production.

the downstream market and the payoffs of all firms are therefore conditional on the supply of input and the results of the product update. The survival probabilities, cost information (including input prices), and decisions of each firm are public knowledge in the vertical structure.

We consider a stage game that contains several phases, as follows.

Pre-innovation phase (stages 1-3): fixing the supply of input.

Stage 1. Firm $A$ proposes a linear supply contract to firm $S$. Firm $S$ decides whether to source from firm $A$ or set up its upstream production (as $S$ will surely survive in the downstream market).

Stage 2. Firm $W$ decides whether to invite firm $A$ into an R&D alliance if $W$ expects to encounter foreclosure based on the public knowledge about costs, etc.

Stage 3. Firm $A$ decides between discouraging firm $W$'s entry with a high input price, or offering a linear supply contract. $A$ also decides whether to join the alliance upon an invitation. The supply contract is non-binding across stages and firm $W$ can deviate to self-production if it succeeds in the product update. In the case of refusal of input supply, firm $W$ is excluded from the market.

Innovation phase (stages 4-5).

Stage 4. Firm $A$ provides the input specified for innovation to its downstream affiliate and external downstream partner(s) that accept firm $A$'s supply contract. This little input has no charge for firm $S$ due to $S$'s flexible upstream entry, and the same for firm $W$ due to its financial constraints.

Stage 5. Each firm conducts product innovation with input.

Post-innovation phase (stages 6-7): production of the new product.

Stage 6. Results of product innovation release. In case of a successful development of product, firm $W$ can decide whether to stick to firm $A$'s supply or quickly set up its upstream affiliate and produce input due to the scant restraints of an incomplete supply contract.

Stage 7. Firms set quantities, and firm $A$ supplies the input for producing the new product for its downstream affiliate if $D_A$ survives, as well as external downstream partners that accomplish the product update and stick to its supply. In case of a failure in the product update, firm $A$ assumes only its role of upstream supplier. The new product comes to market and sales are realized.

### 3.3.1 Discussion of the model

First, this paper mirrors the differences in technological capacity for developing the new final product between firms through the distinct survival probabilities of firms.

Firm $S$ is assumed to be the most mighty one in terms of techniques and financial resources in the downstream market, hence, its survival probability is standardized to 1. As an innovative startup, the downstream entrant $W$ possesses a relatively high survival probability of $h \leq 1$. By contrast, the vertically integrated firm $A$ is more established in the upstream market (manifested by its upstream efficiency advantage), and can hence complete the product update with the lowest probability of $h_A$. Assigning the least good survival propensity to the vertically integrated incumbent is challenging, as large incumbents are usually regarded as embracing more resources than startups and are hence more likely to lead the industrial trends. Yet innovative entrants may report better performance in technique updates and product exploration. An instance in point would be Google's huge list of acquisitions of startups, which well presents the excess value of startups compared to incumbents due to their expertise in a specific field. For example, Google acquired Waze for US$ 1.15 billion in 2013 with the aim of complementing Google's existing map software with Waze's novel real-time traffic data shared by users. In this paper, the superior expertise of firm $W$ is embodied by its higher survival probability.

In addition, the model proposes the possibility of an R&D alliance between firm $A$ and the innovative entrant $W$, and excludes the engagement of firm $S$. It is theoretically beneficial for firm $S$ to collaborate with firm $A$ on innovation and thereby discourage market entry, in which case firm $S$ earns at least the Cournot profit from the softened market competition. Nevertheless, technology leakage arising from technology sharing within R&D alliances is generally severe and unneglectable as the use of know-how knowledge usually cannot be explicitly contracted and properly regulated.[7] Taking into account those concerns, it could be the case that the R&D alliance with firm $S$ will spread its knowledge not only among partners but also cross the alliance's border and reach firm $W$. This would enable firm $W$ to achieve the product update relying on technology leakage rather than on its own innovation efforts and leave it free to enter the upstream market further.[8] The result turns out to be that all firms survive and compete in the downstream market. Therefore, being insulated from an R&D alliance allows firm $S$ to preserve its leading position and to obtain the monopoly profit with a larger propensity.

[7] Technology leakage is a long-standing issue related to R&D alliances. See Frishammar et al. (2015) and Oxley and Sampson (2004) for more thorough discussions.

[8] The innovation process, for example, could be exploring the production formula of a chemical product through experiments. The technical leakage here is equivalent to publishing the product formula to the public. With the off-the-shelf formula, firm $W$ does not need input for experiments and can enter the upstream market as its prospect in the downstream market is assured.

Some empirical evidence for this assumption can be seen in examples from the autonomous car industry. Honda Motor Co. had talks with Waymo LLC, the leading firm in the field of autonomous driving technology, about collaborative development on this technology which finally ended in failure. One prominent contradiction between traditional car manufacturers and technology firms is that traditional firms are more inclined to develop the technology jointly, but large technology firms such as Waymo seek only car suppliers. A similar situation also happened to Apple. Apple once wanted to seek partnerships with Mercedes and BMW to develop all-electric autonomous cars, but talks foundered over Apple's refusal to provide control over data and design.[9]

The R&D alliance between firm $A$ and the entrant discussed in this paper essentially incorporates the technology transfer from firm $W$ to firm $A$.[10] Hence, the entrant is motivated to share its knowledge with firm $A$ if and only if it encounters conditions that discourage firm $A$ from accommodating market entry. Put differently, the technology licensing within the alliance serves as the cost of market entry for firm $W$, and a sort of intangible asset compensation to firm $A$ for its losses resulting from market entry.

It is assumed that firm $S$ can flexibly begin the self-production of input at a marginal cost just slightly higher than firm $A$, with the rationale being that leading firms usually have alternative suppliers and thereby do not face severe input constraints. Therefore, throughout the model, firm $S$ affects the incentive of firm $A$ for vertical foreclosure only through downstream competition and $S$'s corresponding demand for input.

### 3.3.2 Market entry absent the R&D alliance

We first discuss the possibility of market entry when there is no alliance established, and start from the input prices set by firm $A$ to firms $S$ and $W$. Considering the possibilities for upstream entries of the independent downstream firms, firm $S$ will never be foreclosed as it can flexibly enter the upstream market and produce at a marginal cost of $c$. In such a case, supplying firm $S$ at a linear unit price slightly lower than $c$ is profitable for firm $A$, which discourages $S$'s upstream entry and offers $A$ a positive upstream profit. Given collusion is excluded, firm $S$ will accept

[9] See https://www.bizjournals.com/sanjose/news/2016/04/20/bmw-and-daimler-turn-down-apple-in-car-project.htm and https://www.bloomberg.com/news/articles/2018-10-05/honda-waymo-talks-are-said-to-have-faltered-on-tech-access-evs for more details.

[10] Mathews (2006) considers the technology transfer from a small entrepreneurial firm to an entrenched incumbent, too.

this supply contract independent of firm $A$'s decision on market entry, as sourcing from $A$ slightly outperforms self-production.

Firm $W$ can also enter the upstream market, but only after it has been supplied with input for product innovation and finally succeeds. Firm $A$, of course, prefers an input price that extracts the whole profit of $W$, however, given the non-binding supply contract, such a price will encourage $W$ to deviate toward self-production once it has survived. Therefore, firm $A$ can only charge $W$ the same linear unit price that is slightly lower than $c$ in the case of supply, so as to discourage $W$'s follow-up upstream entry and retain its purchase. If firm $A$ has an incentive for vertical foreclosure, it must refuse input supply in the pre-innovation phase so as to prevent firm $W$'s participation in the product innovation.

Given the input prices that firm $A$ will charge in the case of supply, we next consider the simpler case of no product development, that is, all active firms in the market can survive. In the case of refusal to supply firm $W$, firms $A$ and $S$ compete à la asymmetric Cournot in the downstream market since the marginal costs of firms $A$ and $S$ are zero and $c$, respectively. The profit of firm $A$ is

$$\pi_{ne} = \pi^{ca} + \lambda^{ca} = \frac{(1+c)^2}{9} + \frac{(1-2c)\,c}{3}, \tag{3.1}$$

where the superscript $ca$ refers to asymmetric Cournot competition and the subscript $ne$ denotes the basic case in which there is neither product update nor market entry. $\pi^{ca}$ represents the profit of firm $A$ from selling final products in the downstream market and $\lambda^{ca}$ is the upstream profit from supplying input to firm $S$ at the unit price $c$.

In the case of accommodating market entry, firms $A$, $S$ and $W$ compete à la asymmetric oligopoly in the downstream market as firms $S$ and $W$ are equally less efficient than firm $A$. We can denote the profit of firm $A$ by

$$\pi_e = \pi^{oa} + 2\lambda^{oa} = \frac{(1+2c)^2}{16} + \frac{(1-2c)\,c}{2}, \tag{3.2}$$

where the superscript $oa$ refers to asymmetric oligopoly competition and the subscript $e$ denotes the alternative basic case in which there is no product update but market entry. Hence, $\pi^{oa}$ is the downstream profit and $2\lambda^{oa}$ is the upstream profit from supplying input to the independent downstream firms. Notice that $\pi_e < \pi_{ne}$ in the whole parameter interval of $c$, namely firm $A$ will foreclose firm $W$ on input if $A$ does not face risks of survival.

Next, we expand to the equilibrium analysis with product innovation taken into account based on the above basic profits $\pi_{ne}$ and $\pi_e$. Conditional on the decision of firm $A$ on whether to accommodate downstream entry and whether firms $W$ and $A$ reach an R&D alliance, there are three possible results: (1) Firm $A$ refuses input supply to firm $W$; (2) Firm $W$ is supplied but does not reach an R&D alliance with firm $A$; (3) Firm $W$ enters the market through the R&D alliance. In this section, we focus on the first two cases.

In the first case where firm $A$ forecloses firm $W$ on input, firm $A$ competes with firm $S$ through its own innovation capacity and the expected profit of $A$ is

$$\begin{aligned}\Pi_1 &= h_A \pi_{ne} + (1 - h_A)\, \lambda^m \\ &= \frac{1}{18}\,(h_A + 9)\,(1 - c)\, c + \frac{h_A}{9},\end{aligned} \tag{3.3}$$

where the superscript $m$ refers to firm $S$ monopolizing the market. The first term then represents the profit in the scenario where firms $A$ and $S$ both survive, and the second term represents the profit in the opposite scenario where firm $A$ fails in the product update and earns only in the upstream market for supplying firm $S$ with an input of monopoly quantity.

In the second case where firm $W$ is supplied with a necessary amount of input for its innovation process without the help of the R&D alliance, there are four possible scenarios regarding firms $A$ and $W$'s survival or withdrawal in the downstream market:

(a) With a probability of $h_A h$, both firms $A$ and $W$ survive. Oligopoly competition takes place and firm $A$ earns $\pi_e$.

(b) With a probability of $h_A(1 - h)$, firm $A$ is active but firm $W$ is out. Cournot competition takes place and firm $A$ earns $\pi_{ne}$.

(c) With a probability of $(1 - h_A)h$, firm $W$ is in but firm $A$ is out. Firms $S$ and $W$ compete at equal marginal costs (i.e., $c$). As a result, firm $A$ earns the upstream profit of supplying input to firms $S$ and $W$, $2\lambda^c$, with the superscript $c$ representing symmetric Cournot competition.

(d) With a probability of $(1 - h_A)(1 - h)$, firms $A$ and $W$ both fail in the product update and exit the downstream market. Firm $S$ produces monopoly quantity and thus provides firm $A$ with an upstream profit of $\lambda^m$.

The expected profit of firm $A$ in the second case is hence

$$\begin{aligned}\Pi_2 &= h_A \left[h\pi_e + (1 - h)\, \pi_{ne}\right] + (1 - h_A)\left[2h\lambda^c + (1 - h)\, \lambda^m\right] \\ &= \frac{1}{144}\left[(4h + 8)\, h_A + 24h + 72\right](1 - c)\, c + \frac{1}{144}\,(16 - 7h)\, h_A.\end{aligned} \tag{3.4}$$

The principle of firm $A$ in accommodating market entry is that the market entry brings excess returns to firm $A$ with respect to vertical foreclosure. Therefore, the difference between $\Pi_1$ and $\Pi_2$ presents the least condition that firm $W$ needs to meet to enter the market without the help of an R&D alliance. Denote the difference of $\Pi_2 - \Pi_1$ as $\triangle_1$ which is given by

$$\begin{aligned} \triangle_1 &= h\left[h_A\left(\pi_e - \pi_{ne}\right) + \left(1 - h_A\right)\left(2\lambda^c - \lambda^m\right)\right] \\ &= \frac{h}{36}\left(h_A + 6\right)\left(1 - c\right)c - \frac{7h\,h_A}{144}. \end{aligned} \tag{3.5}$$

The first and second terms in the square brackets on the right-hand side of equation (3.5) are, respectively, given the successful downstream entry of firm $W$, the expected loss of firm $A$ due to the fiercer competition in the case of its survival, and the expected gain of $A$ due to an enlarged demand for input in the case of its exit. $\triangle_1$ hence indicates the incentive of firm $A$ for vertical foreclosure: a negative $\triangle_1$ stands for a net loss and motivates firm $A$ for foreclosure, while a positive $\triangle_1$ stands for a net gain and facilitates market entry. Moreover, the sign of the net value is independent of how likely it is firm $W$ will survive survives but only dependent on the survival probability and cost advantage of firm $A$, as the failure to innovate of firm $W$ is equivalent to no market entry and does not generate additional effects on firm $A$'s profit.

A threshold of $h_A$ derived from the equation $\triangle_1 = 0$ is,

$$h_A^B\left(c\right) = \frac{24c\left(1 - c\right)}{4c^2 - 4c + 7}, \tag{3.6}$$

at which point firm $A$ is indifferent to accommodating market entry or applying vertical foreclosure. Proposition 3.1 describes the feasible zone of market entry in the absence of an R&D alliance.

**Proposition 3.1.** *As $\triangle_1$ is decreasing in $h_A$, firm $W$ can successfully enter the market without the help of an R&D alliance only when $h_A \leq h_A^B\left(c\right)$. Otherwise, firm $W$ will be foreclosed on input and discouraged from entry.*

### 3.3.3 The role of an R&D alliance on entry

The above analysis demonstrates that given no R&D alliance has been established, $h_A^B\left(c\right)$ defines the boundary of the feasible zone for market entry. Namely, vertical foreclosure occurs if firm $A$ expects to survive on its own with a relatively high probability (i.e., $h_A > h_A^B\left(c\right)$), to which a related question is whether the R&D

alliance can provide firm $W$ with access to input and facilitate market entry. To answer this question, we move on to the third case in which firm $A$ reaches an R&D alliance with firm $W$.

Under an R&D alliance, firm $A$ benefits from technology licensing and masters the entire knowledge of firm $W$ for the product update. Firms $A$ and $W$ will either jointly survive with a probability of $h$ or withdraw from the downstream market with a probability of $1-h$. Firm $A$ reaps the profit of $\pi_e$ if $D_A$ survives, or the upstream profit $\lambda^m$ for supplying firm $S$ if $D_A$ exits. Therefore, the expected profit of firm $A$ is

$$\begin{aligned}\Pi_3 &= h\pi_e + (1-h)\,\lambda^m \\ &= \frac{1}{16}\,(4h+8)\,(1-c)\,c + \frac{h}{16}.\end{aligned} \tag{3.7}$$

We denote the difference of $\Pi_3 - \Pi_1$ as $\triangle_2$, which is

$$\begin{aligned}\triangle_2 &= h\,(\pi_e - \lambda^m) - h_A\,(\pi_{ne} - \lambda^m) \\ &= \frac{1}{144}\,(36h - 8h_A)\,(1-c)\,c + \frac{h}{16} - \frac{h_A}{9}.\end{aligned} \tag{3.8}$$

$\triangle_2$ represents the gains or losses of firm $A$ from an R&D alliance with respect to the case of no market entry. The threshold of $h_A$ that makes firm $A$ indifferent to reaching an R&D alliance or vertical foreclosure is derived from the equation $\triangle_2 = 0$ as

$$h_A^{RD}\,(h,c) = \frac{9h\left(4c^2-4c-1\right)}{8\,(c^2-c-2)}. \tag{3.9}$$

The threshold $h_A^{RD}\,(h,c)$ increases as the R&D alliance offers a higher probability of survival to its partners and achieves the maximum at the point $h=1$. Since $\triangle_2$ is decreasing in $h_A$, the entrant $W$ can enter the market through the R&D alliance if and only if $h_A \leq h_A^{RD}\,(h,c)$. The threshold of $c$ in the interval $\left(0, \frac{1}{2}\right]$ for which $h_A^{RD}\,(h,c)$ equals $h_A^{B}\,(c)$ is

$$c^B\,(h) = \frac{3h+4-\sqrt{2\,(3h+4)\left(10-3h-\sqrt{36h^2-51h+64}\right)}}{6h+8}. \tag{3.10}$$

The feasible zone of market entry, however, is not necessarily enlarged by the R&D alliance, as $h_A^{RD}\,(h,c)$ may be lower than $h_A^{B}\,(c)$. Lemma 3.1 presents the comparison between $h_A^{RD}\,(h,c)$ and $h_A^{B}\,(c)$.

**Lemma 3.1.** *As $h_A^{RD}\,(h,c) - h_A^{B}\,(c)$ decreases in $c$, $h_A^{RD}\,(h,c) \geq h_A^{B}\,(c)$ if $c \leq$*

$c^B(h)$, $h_A^{RD}(h,c) < h_A^B(c)$ *otherwise.*

Hence, $c^B(h)$ defines the boundary of the effectiveness of an R&D alliance in facilitating market entry (hereafter, the effectiveness boundary, for brevity). Lemma 3.2 provides the monotonicity of $c^B(h)$.

**Lemma 3.2.** $c^B(h)$ *rises as* $h$ *increases.*

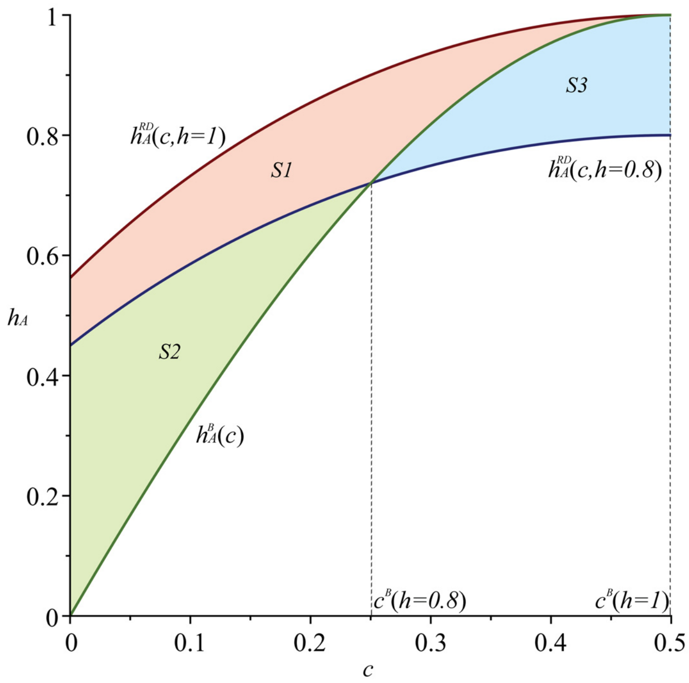
Lemma 3.2 implies that the effectiveness boundary of the R&D alliance enlarges as firm $W$ is more advantageous with respect to firm $A$ in terms of the product update. Figure 3.1 illustrates the changes in the feasible zone of market entry under the R&D alliance when $h = 1$ and $h = 0.8$. When $h = 1$, alliance partners certainly complete the product update and survive in the downstream market. The R&D alliance thus moves the boundary of the feasible zone of market entry from $h_A^B(c)$ to $h_A^{RD}(c,h)\big|_{h=1}$ and the effectiveness of the alliance in mitigating vertical foreclosure is the size of the area $S1 + S2$. When the probability of survival decreases to 0.8 for partners, the boundary of the feasible zone of market entry moves to $h_A^{RD}(c,h)\big|_{h=0.8}$. The effectiveness of the R&D alliance in dispelling vertical foreclosure shrinks to only the size of the area $S2$. In the interval where $c > c^B(h)\big|_{h=0.8}$, vertical foreclosure will be exacerbated if the R&D alliance is established, thus preventing firm $W$ from reaching an alliance. Along with the survival probability of alliance partners declines, the threshold $c^B(h)$ moves to the left, implying the reduced effectiveness of the alliance in stimulating market entry.

Proposition 3.2 summarizes the role of the R&D alliance in eliminating vertical foreclosure.

**Proposition 3.2.** *The R&D alliance facilitates market entry when* $c \leq c^B(h)$, *yet provides no help on fixing vertical foreclosure and is therefore excluded from the tactics of firm* $W$ *when* $c > c^B(h)$.

The mechanism behind the results is the trade-off of firm $A$ between the upstream and downstream profits. When the individually accumulated knowledge can provide firm $A$ with a high survival probability (i.e., $h_A > h_A^B(c)$), firm $A$ will discourage the entry of firm $W$ so as to ease market competition in the absence of the R&D alliance. Consider a scenario in which the alliance guarantees a higher propensity of survival, taking $h = 0.8$ as an example, and the marginal cost advantage of firm $A$ is modest (i.e., $c \leq c^B(h)\big|_{h=0.8}$). In this case, the market entry brings about a significant increase in downstream output and thereby a remarkable growth in the upstream profit for firm $A$. Although the downstream profit in the

Figure 3.1: Changes in the feasible zone of market entry




case of survival decreases to an oligopoly profit, the R&D alliance provides firm $A$ with a more promising prospect of obtaining the downstream profit. Consequently, firm $A$ is more prone to give approval for the input supply to the entrant. When the marginal cost advantage of firm $A$ is relatively large (i.e., $c > c^B(h)\big|_{h=0.8}$), the upstream gain of firm $A$ brought about by reaching the alliance is limited due to the great cost disadvantage of firm $W$, leading the downstream loss to exceed the upstream gain. $A$ will be motivated to foreclose firm $W$ on input while facing the alliance proposal. Reaching an alliance is therefore out of the options of firm $W$ in this case.

## 3.4 Variants of the model

In this section, we discuss several variants that relax different assumptions of the benchmark model, and examine the effectiveness of the R&D alliance in alleviating the vertical foreclosure that occurs in various market environments.

### 3.4.1 Backward spillovers in the supply chain

As stated in section 3.2, an enlarging body of theoretical and empirical evidence addresses the prevalence and significance of backward spillovers in supply chains.

In the business world, the extent and scope of backward spillovers are staggering, with the long-standing history of cooperation and competition between Samsung Inc. and Apple Inc. being a good example. Stemming from selling hard drives and memory chips to Apple, Samsung has gradually become one of the main component suppliers of Apple in the past decades. After years of supplying Apple and seeing the success of the iPod and iPhone, Samsung started to initiate some similar substitutes based on its accumulated knowledge of the iPod and iPhone from the supply partnership. As a report says: "[...] Samsung went so far in its attempts to compete with the iPhone that it made all of its app icons square and made its menus look almost exactly like Apple's. Ask anyone familiar with Samsung's phones and they will tell you that, for a while, they were so Apple-like that it was kind of silly" (Paragraph 5 of the report).[11] The increasingly fierce war between Apple and Samsung involving iPhone and Galaxy-related patents is also proof. In such a relationship that is more competition than cooperation, Apple began to consciously reduce its dependence on Samsung and shifted to other suppliers, according to a report from Nikkei Asian Review.[12]

The way of cooperation between leading firms in autonomous driving technology and their car suppliers conveys the same concerns of technology giants. For example, when it comes to the connection with upstream suppliers, the pioneering firm Waymo only pursues partners that supply customized cars instead of letting the partners engage in the R&D process of technology. The upstream suppliers are not even allowed to assemble the autonomous cars due to technology leakage concerns.

In the present model, backward spillovers can occur in the vertical connection between firms $A$ and $S$, as firm $S$ has a more outstanding performance in product update and may generate spillovers to firm $A$ through employee mobility or informal talks between employees of the two firms.[13] Therefore, this section focuses on the influences of backward spillovers on an R&D alliance's effectiveness in eliminating vertical foreclosure. Firm $A$ is assumed to improve its propensity for the product update to $H_A \geq h_A$ by virtue of the backward spillovers of firm $S$ at a cost of $f_A(H_A)$. However, backward spillovers are not supposed to reveal all the core

[11] See `https://www.digitaltrends.com/android/samsung-copied-apple-who-cares/` for more details.

[12] Although Apple has repeatedly paid steep charges to Samsung for panel screen orders below the predetermined level, Apple is still trying to diversify screen suppliers. To this end, Apple has listed LG and China BOE as alternatives. See `https://asia.nikkei.com/Business/Electronics/Apple-s-OLED-supplier-shift-gives-LG-fighting-chance-against-Samsung` for more details.

[13] See Javorcik (2004) for a more thorough discussion about the forms of spillovers.

technologies of firm $S$, hence the impacts of backward spillovers on innovation for firm $A$ are assumed to be no larger than the technology transfer within an R&D alliance and $H_A \leq h$. The cost of absorbing and utilizing spillovers, $f_A = k\left(H_A - h_A\right)$, with $k > 0$ the unit absorptive cost, is increasing in $H_A$.

This assumption is not only supported by the evidence stated above, but also based on the following considerations. Since the new product is assumed to be updated on the basis of the old one and the two generations of products are perfect substitutes, the majority of their manufacturing process should at least be similar. Besides, firm $A$ has experience in producing and selling the old generation of product in the downstream market, implying that firm $A$ has extensive knowledge and skills in downstream production. Furthermore, firms need a certain absorptive capacity to learn spillovers and then fit and apply the external knowledge to their own applications, and investments in R&D activities can enhance this capacity and help to better utilize spillovers (Leahy and Neary, 2007). Added up, all of this leads to the fact that firm $A$ is familiar with the production process of the new product, and the technical difficulties of firm $A$ in the product update might be some implicit directions on certain core links, though appropriating the backward spillovers takes cost.[14]

**Entry absent the R&D alliance.** Since the expected profit of firm $A$ in cases that are composed of different configurations of active firms can be expressed as the function of firm $A$'s survival probability, such as $\Pi_i\left(h_A\right)$, $i = 1, 2, 3$ in the benchmark model, the expected profits of firm $A$ in the presence of backward spillovers are then the function of its new survival probability $H_A$. We first look at the market entry absent an R&D alliance.

(1) In the case that firm $A$ refuses to supply firm $W$, firm $A$'s expected profit is

$$\Pi_1^{BS}\left(H_A\right) = \Pi_1\left(H_A\right) - f_A\left(H_A\right), \tag{3.11}$$

where the superscript $BS$ represents the case of backward spillovers. As the unit absorptive cost derives firm $A$'s decision regarding spillovers, the derivative of $\Pi_1^{BS}\left(H_A\right)$ with respect to $H_A$ is obtained as

$$\frac{\partial \Pi_1^{BS}\left(H_A\right)}{\partial H_A} = \frac{c\left(1-c\right)+2}{18} - k. \tag{3.12}$$

Apparently, a higher survival probability is associated with a higher profit if

[14] For example, improvements in the performance of aluminum alloy sheets, such as the substantial increase in strength, may come from changes in separate preparation parameters, and how to adjust the parameters is the key to production.

$k \leq k_1 = \frac{c(1-c)+2}{18}$, and otherwise a lower profit. Firm $A$ will therefore make full use of spillovers and improve its survival probability to $h$ if $k \leq k_1$, at a cost of $k(h - h_A)$. On the contrary, $A$ will compete under its original survival probability if $k > k_1$, in which case innovation by means of spillovers is costly and undermines profit.

(2) In the case that firm $W$ is supplied but does not reach an R&D alliance with firm $A$, $A$'s expected profit becomes

$$\Pi_2^{BS}(H_A) = \Pi_2(H_A) - f_A(H_A). \tag{3.13}$$

The derivative of $\Pi_2^{BS}(H_A)$ with respect to $H_A$ is given by

$$\frac{\partial \Pi_2^{BS}(H_A)}{\partial H_A} = \frac{c(1-c)(4h+8) - 7h + 16}{144} - k. \tag{3.14}$$

Likewise, if $k \leq k_2 = \frac{c(1-c)(4h+8)-7h+16}{144}$, firm $A$ will improve its survival probability to $h$ with spillovers and will otherwise not spend any costs on spillovers if $k > k_2$.

Given $k_1 \geq k_2$, the decision of firm $A$ on whether to make use of spillovers (Yes/No) and the resulted expected profit in the case with or without market entry can be summarized as in Table 3.1 below. Besides, $\triangle_1^{BS} = \Pi_2^{BS}(H_A) - \Pi_1^{BS}(H_A)$, reported in Table 3.1 as well, is the gains or losses of firm $A$ from accommodating market entry without entering an R&D alliance in the presence of backward spillovers.

Table 3.1: Firm $A$'s decision on spillovers, resulted profit, and the difference in profits

| | No market entry | With market entry | $\triangle_1^{BS}$ |
|---|---|---|---|
| | Decision (Yes/No) and $\Pi_1^{BS}$ | Decision (Yes/No) and $\Pi_2^{BS}$ | |
| $k \leq k_2$ | Yes, $\Pi_1^{BS}(h)$ | Yes, $\Pi_2^{BS}(h)$ | $\triangle_1(h_A \mid h_A = h)$ |
| $k_2 < k \leq k_1$ | Yes, $\Pi_1^{BS}(h)$ | No, $\Pi_2^{BS}(h_A)$ | $\Pi_2^{BS}(h_A) - \Pi_1^{BS}(h)$ |
| $k > k_1$ | No, $\Pi_1^{BS}(h_A)$ | No, $\Pi_2^{BS}(h_A)$ | $\triangle_1(h_A)$ |

An implication from Table 3.1 is that the case with $k > k_1$ where firm $A$ gives up on exploiting spillovers regardless of $W$'s entry, is exactly the same as in the benchmark model. Lemma 3.3 then depicts the monotonicity of $\triangle_1^{BS}$.

**Lemma 3.3.** *$\triangle_1^{BS}$ increases in $c$, and increases in $k$ when $k_2 < k \leq k_1$.*

The solution to the equation $\triangle_1^{BS} = 0$ defines the boundary of the feasible zone for market entry and implies the conditions under which firm $A$ approves the input supply for the entrant. Given a non-negative unit absorptive cost for spillovers, the entry boundary as well as entry conditions may be determined by a set of equations, which are therefore reported in Table 3.2.

Table 3.2: Entry boundary and conditions in the absence of an R&D alliance

| | Entry boundary | Conditions for market entry |
|---|---|---|
| $k \leq k_2$ | $c_1 = \frac{h+6-\sqrt{36-30h-6h^2}}{2h+12}$ | $c \geq c_1$ |
| $k_2 < k \leq k_1$ | $k^{BS} = \frac{h_A\left[\left(4c-4c^2-7\right)h-8c^2+8c+16\right]-16h\left(c^2-c+1\right)}{144(h_A-h)}$, $c_2 = \frac{h_A+6-\sqrt{36-30h_A-6h_A^2}}{2h_A+12}$ | $k \geq k^{BS}$ and $c \geq c_2$ |
| $k > k_1$ | $c_2$ | $c \geq c_2$ |

The second condition ($c \geq c_2$) for market entry when $k_2 < k \leq k_1$ is derived from the criteria of $k^{BS} \leq k_1$. The entry boundary when $k > k_1$ is the reverse function of $h_A^B(c)$ that is obtained in the benchmark model. We report the reverse function instead of $h_A^B(c)$ to better compare with the boundaries in the other cases. Notice that $c_1 > c_2$ demonstrates a narrower feasible zone for an entry indicating vertical foreclosure is more prone to arise as the cost for appropriating spillovers shrinks.

**Entry under the R&D alliance.** We next examine how an R&D alliance changes the incentive of firm $A$ for vertical foreclosure. Consider that firm $W$ enters the market via the R&D alliance and shares its innovation knowledge with firm $A$, $A$ then improves its survival probability to $h$ without putting effort into studying spillovers, and achieves an expected profit of

$$\Pi_3^{BS}(h) = \Pi_3(h). \tag{3.15}$$

The net benefits or losses from the alliance for firm $A$ compared to the case of no market entry is represented by $\triangle_2^{BS}$, namely the difference of $\Pi_3^{BS} - \Pi_1^{BS}$. $\Pi_1^{BS}$ is conditional on the unit absorptive cost, as firm $A$ will take advantage of spillovers and achieve an augmented survival probability of $h$ if the unit absorptive cost (i.e., $k$) is no more than $k_1$, or does not invest in its abortive capacity and innovate on its own technology if $k > k_1$. $\triangle_2^{BS}$ is given by

$$\triangle_2^{BS} = \begin{cases} \Pi_3^{BS}(h) - \Pi_1^{BS}(h) = \frac{h[28c(1-c)+144k-7]-144kh_A}{144},\ if\, k \leq k_1, \\ \Pi_3^{BS}(h) - \Pi_1^{BS}(h_A) = \triangle_2(h_A),\ if\, k > k_1. \end{cases} \tag{3.16}$$

The boundary of the feasible zone for market entry given an R&D alliance is summarized in equation (3.17).

$$boundary\ equation = \begin{cases} k^{BS,RD} = \frac{7h(4c^2-4c+1)}{144(h-h_A)},\ if\, k \leq k_1, \\ h_A^{RD},\ if\, k > k_1, \end{cases} \tag{3.17}$$

where $h_A^{RD}$ is the one obtained from the benchmark model in the case of an alliance.

Lemma 3.4 gives the monotonicity of $\triangle_2^{BS}$ and $k^{BS,RD}$.

**Lemma 3.4.** *$\triangle_2^{BS}$ is increasing in $k$. $k^{BS,RD} - k_1$ is decreasing in $c$.*

The entry condition in the case of $k \leq k_1$ is therefore $k \geq k^{BS,RD}$, which gives a higher post-entry profit to firm $A$ compared to no market entry. Naturally, $k^{BS,RD} \leq k_1$ is the prerequisite for $k^{BS,RD}$ to be a meaningful boundary differentiating successful and unsuccessful attempts of market entry, for which the complementary condition is equation (3.18).

$$c \geq c_3 = \frac{2h_A - 9h + 3\sqrt{4h_A^2 - 22h_Ah + 18h^2}}{4h_A - 18h}. \tag{3.18}$$

Combining equations (3.17) and (3.18), and Lemma 3.4, Proposition 3.3 describing the conditions for a feasible market entry is obtained.

**Proposition 3.3.** *Market entry through the R&D alliance can occur in the presence of backward spillovers, as long as $k \geq k^{BS,RD}$ and $c \geq c_3$ given $k \leq k_1$, or $h_A \leq h_A^{RD}$ given $k > k_1$.*

**Is the R&D alliance additionally helpful?** We study the role of an R&D alliance in facilitating market entry by focusing on the comparison of the entry conditions under the alliance to these absent an alliance. Since the entry conditions vary across different subintervals of the unit absorptive cost, we conduct the comparison by cases of distinct values of $k$.

When the unit absorptive cost is low ($k \leq k_2$), the entry condition is $c \geq c_1$ if there is no alliance, and is $k \geq k^{BS,RD}$ and $c \geq c_3$ if firms $A$ and $W$ reach the alliance. The alliance can be regarded as effective in promoting market entry only if the threshold of efficiency drops (i.e., $c_3 \leq c_1$), given $k^{BS,RD} \leq k_2$ is satisfied. Lemmas 3.5 and 3.6 correspondingly result from the two requirements and present the size relationship between $k^{BS,RD}$ and $k_2$, $c_1$ and $c_3$, respectively.

**Lemma 3.5.** *As $k^{BS,RD} - k_2$ increases in $h_A$, $k^{BS,RD} \leq k_2$ if $h_A \leq h_{A,1} = \frac{h[c(c-1)(36+4h)+7h-9]}{c(c-1)(8+4h)+7h-16}$.*

**Lemma 3.6.** *As $c_3 - c_1$ increases in $h_A$, $c_3 \leq c_1$ if $h_A \leq h_{A,2} = \frac{3h(4h+3)}{5h+16}$.*

Proposition 3.4 summarizes the conditions for an R&D alliance to provide additional access to input for the entrant compared to the case without the alliance, given a low unit absorptive cost.

**Proposition 3.4.** *Vertical foreclosure can be fixed by an R&D alliance if $k \geq k^{BS,RD}$ and $h_A \leq min\{h_{A,1}, h_{A,2}\}$, given $k \leq k_2$.*

When the unit absorptive cost is medium-high ($k_2 < k \leq k_1$), the entry condition becomes $k \geq k^{BS}$ and $c \geq c_2$ absent an alliance. Only when the thresholds of the absorptive cost and the efficiency are both lowered by the alliance (i.e., $k^{BS,RD} \leq k^{BS}$ and $c_3 \leq c_2$), can it demonstrate the stimulation of the alliance on market entry. Lemmas 3.7 and 3.8 generate in the comparison between $k^{BS,RD}$ and $k^{BS}$, $c_2$ and $c_3$, respectively.

**Lemma 3.7.** *As $k^{BS,RD} - k^{BS}$ increases in $h_A$, $k^{BS,RD} \leq k^{BS}$ if $h_A \leq h_{A,3} = \frac{3h(4c^2-4c-3)}{(c^2-c)(4h+8)+7h-16}$.*

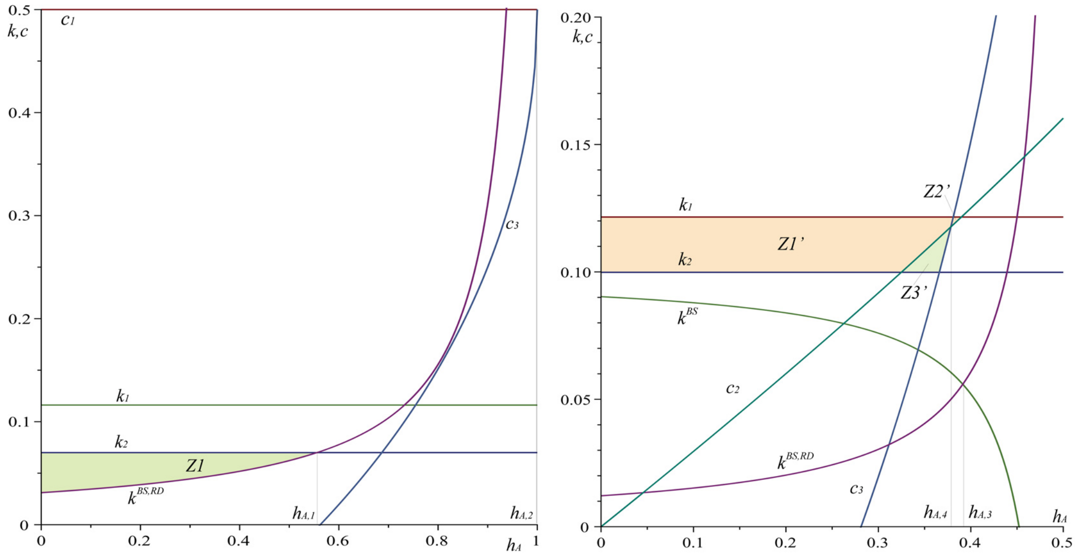
**Lemma 3.8.** *As $c_3 - c_2$ increases in $h_A$, $c_3 \leq c_2$ if $h_A \leq h_{A,4} = \frac{6h-8+\sqrt{36h^2-51h+64}}{5}$.*

Proposition 3.5 then gives the condition under which an R&D alliance is effective in gaining better access to input for the entrant in case of a medium-high unit absorptive cost.

**Proposition 3.5.** *Vertical foreclosure can be fixed by an R&D alliance if $k \geq k^{BS,RD}$ and $h_A \leq min\{h_{A,3}, h_{A,4}\}$, given $k_2 < k \leq k_1$.*

A high absorptive cost ($k > k_1$) will discourage firm $A$ from employing spillovers in any cases, and the effectiveness of an R&D alliance in mitigating vertical foreclosure refers to the benchmark model. One far-reaching implication from the analysis in this section for the industry is that although backward spillovers generate more growth opportunities for upstream firms, if upstream industry giants controlling one or several necessary inputs only pay little for appropriating these

Figure 3.2: Changes in market entry barrier given backward spillovers




(a) $k \leq k_2, c = 0.1, h = 1$

(b) $k_2 < k \leq k_1, c = 0.25, h = 0.5$

spillovers, innovative downstream startups possessing superior knowledge may encounter more severe entry restraints.

Figure 3.2 above is an illustration of the changes in entry boundaries induced by the R&D alliance in cases of different unit absorptive costs. When the unit absorptive cost is low ($k \leq k_2$), as shown in Figure 3.2(a), given $c = 0.1$ and $h = 1$, $c_1 = 0.5$ implies that vertical foreclosure definitely happens if the entrant does not license its technology to the vertically integrated incumbent. If, alternatively, the alliance is established and technology licensing occurs, the feasible zone for a market entry is the green area (i.e., $Z1$) bounded by $k_2$ and $k^{BS,RD}$, where $c = 0.1 > c_3$ is satisfied. The effectiveness of the alliance in reducing vertical foreclosure is hence the size of $Z1$. Figure 3.2(b) presents the case of a medium-high unit absorptive cost ($k_2 < k \leq k_1$). Given $c = 0.25$ and $h = 0.5$, the entrant is supplied with input in the absence of an alliance if $k \leq k^{BS}$ and $c \leq c_2$, with the feasible zone of market entry equal to the orange area (i.e., $Z1' + Z2'$) . Under the R&D alliance, the entry conditions are $c \leq c_3$ and $k \leq k^{BS,RD}$ and the feasible zone becomes $Z1' + Z3'$. The effectiveness of the alliance is therefore the size of the green area (i.e., $Z3'$). It's noteworthy that $Z2'$ is the area that supports market entry given no alliance yet the area that prevents market entry given an alliance, hence firm $W$ will not apply the strategic alliance in the parameter intervals of $Z2'$.

### 3.4.2 Multi-market linkage

It is more common for firms to deploy in multiple related industries and markets to deal with demand shocks and expanding market shares, among these firms R&D alliances are also prevalent and bear deeper intentions. In view of this, we next expand the benchmark model from a single downstream market to multiple downstream markets that are asymmetrically accessible to firms, namely, firms can sell the final products in different amounts of markets. A case in point is the R&D alliance between Toyota Motor Co. and Uber Technologies, Inc. on the joint-development of autonomous driving technology. With the continuous advancement of this technology, the application scenarios of autonomous cars in the near future continue to flourish, with the online ride-hailing market becoming another promising turf. The R&D alliance between Uber and Toyota is interpreted as bringing more significance to Toyota for its deployment in the online ride-hailing market, in areas other than technology, as the partnership between Toyota and Uber allows it to stand out from many car manufacturers and assume the role of supplier for Uber's future delivery of autonomous cars in the online ride-hailing market.

We then examine how multi-market linkage changes the feasible zone of market entry and the effectiveness of the R&D alliance in mitigating vertical foreclosure. As when asymmetrically available markets are linked to firms, the entry in one market generates linkage effects to the incumbents and affects vertical foreclosure. In this variant, firms $S$ and $W$ are assumed to sell in markets 1 and 2 if they successfully develop the new product. Demands in the two markets are independent. The vertically integrated upstream monopolist $A$, however, only sells in market 1. The assumption of the asymmetrically available markets among firms aims to explore firm $A$'s motivation for foreclosure when the downstream entry affects $A$'s profit in one tier of the vertical structure through more channels. The reason for asymmetrically available markets may be the geographical location. For example, markets 1 and 2 are far apart and only firms $S$ and $W$ have sales outlets in both markets. Another reason could be whether firms participate in export. It could be that firm $A$ sells only in the domestic market, while firms $S$ and $W$ sell in the domestic as well as foreign markets. Alternatively, it may be that firm $A$ does not have a sales license in market 2. The other aspects remain the same with the benchmark model.

Likewise to the benchmark model, the analysis for this variant begins with the basic cases absent the product update. With the superscript $M$ representing the case of multiple markets, we denote the profits of firm $A$ in the case of vertical foreclosure by $\pi^M_{ne}$, and in the case of accommodating market entry by $\pi^M_e$,

$$\pi^M_{ne} = \underbrace{\pi^{ca} + \lambda^{ca}}_{\text{market 1}} + \underbrace{\lambda^m}_{\text{market 2}} = \frac{19}{18}(1-c)\,c + \frac{1}{9}, \tag{3.19}$$

$$\pi^M_e = \underbrace{\pi^{oa} + 2\lambda^{oa}}_{\text{market 1}} + \underbrace{2\lambda^c}_{\text{market 2}} = \frac{17}{12}(1-c)\,c + \frac{1}{16}, \tag{3.20}$$

where $\lambda^m$ and $\lambda^c$ are separately the upstream profit of supplying input of monopoly quantity and symmetric Cournot quantity for the production of products sold in market 2.

We next consider the product update. In the first case, where firm $A$ refuses to supply firm $W$ but supplies firm $S$, firm $A$ either competes with $S$ in market 1 or exits, firm $S$ monopolises market 2 in both scenarios. The expected profit of firm $A$ is

$$\begin{aligned}\Pi^M_1 &= h_A \pi^M_{ne} + 2(1-h_A)\,\lambda^m \\ &= \left(1 + \frac{h_A}{18}\right) c\,(1-c) + \frac{h_A}{9}.\end{aligned} \tag{3.21}$$

In the case of firm $A$ accommodating the market entry absent an R&D alliance, the competitions in market 1 in different scenarios are the same as described in section 3.3.2. In market 2, firm $S$ either provides monopoly quantity to consumers if firm $W$ exits, or competes with firm $W$ at equal marginal costs. The expected profit of firm $A$ is given by

$$\begin{aligned}\Pi^M_2 &= h_A\left[h\pi^M_e + (1-h)\,\pi^M_{ne}\right] + (1-h_A)\left[4h\lambda^c + 2(1-h)\,\lambda^m\right] \\ &= \frac{1}{144}\left[(4h+8)\,h_A + 48h + 144\right](1-c)\,c + \frac{1}{144}(16-7h)\,h_A.\end{aligned} \tag{3.22}$$

In the case of firms $A$ and $W$ reaching an R&D alliance, firm $A$ profits $\pi^M_e$ given they jointly survive, or profits only from supplying an input of double monopoly quantity to firm $S$ given $A$ and $W$ jointly exit. Firm $A$'s expected profit is hence

$$\begin{aligned}\Pi^M_3 &= h\pi^M_e + 2(1-h)\,\lambda^m \\ &= \left(1 + \frac{5h}{12}\right) c\,(1-c) + \frac{h}{16}.\end{aligned} \tag{3.23}$$

These expected profits of firm $A$ resemble those of the benchmark model.

However, the additional upstream profit from market 2 essentially affects the incentive of firm $A$ for vertical foreclosure. In the present variant, the boundary of the feasible zone of market entry in the absence of an R&D alliance is $h_A^M(c)$ solved from $\Pi_1^M = \Pi_2^M$, and in the presence of an R&D alliance is $h_A^{M,RD}(c,h)$ solved from $\Pi_1^M = \Pi_3^M$, which are respectively

$$h_A^M(c) = \frac{48c(1-c)}{(4c^2-4c+7)}, \tag{3.24}$$

$$h_A^{M,RD}(c,h) = \frac{3h\left(20c^2-20c-3\right)}{8\left(c^2-c-2\right)}. \tag{3.25}$$

Since $\Pi_2^M - \Pi_1^M$ and $\Pi_3^M - \Pi_1^M$ both are decreasing in $h_A$, market entry occurs if $h_A \leq h_A^M(c)$ or $h_A \leq h_A^{M,RD}(c,h)$ in the corresponding case. The threshold that determines the effectiveness boundary of the R&D alliance in fixing foreclosure, resulting from $h_A^{M,RD}(c,h) = h_A^M(c)$, is

$$c^M(h) = \frac{5h+8-\sqrt{-(5h+8)\left(11h+\sqrt{361h^2-856h+1024}-40\right)}}{10h+16}. \tag{3.26}$$

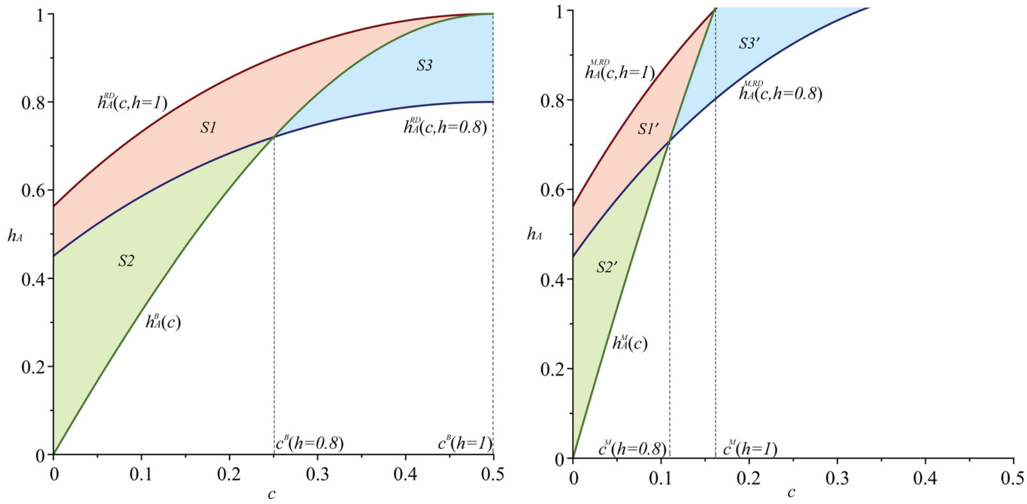
Proposition 3.6 details the effectiveness of the R&D alliance in reducing vertical foreclosure.

**Proposition 3.6.** *As $h_A^{M,RD}(c,h) - h_A^M(c,h)$ decreases in $c$, given multi-market linkage, the R&D alliance relieves vertical foreclosure if $c \leq c^M(h)$.*

Figure 3.3 compares the effectiveness of the R&D alliance in the present variant to that of the benchmark model. The difficulty of market entry is greatly reduced in the case of multi-market linkage as the feasible zone of market entry enlarges even absent an R&D alliance (i.e., $h_A^M(c) > h_A^B(c)$), due to the upstream profit of supplying for the production for market 2. The entrant $W$ faces vertical foreclosure only in the left area of $h_A^M(c)$ and needs to decide whether to achieve market entry through the R&D alliance. The R&D alliance can still overcome vertical foreclosure as long as $c \leq c^M(h)$ and its effectiveness is respectively the size of area $S1' + S2'$ when $h = 1$, and $S2'$ when $h = 0.8$.

Moreover, the boundary of the feasible zone given an R&D alliance in the present variant is higher than that of the benchmark model (i.e., $h_A^{M,RD} > h_A^{B,RD}$) implying more opportunities for market entry. Taking the point $(c = 0.1, h_A = 0.8)$ as an example. This point is beyond the scope of the feasible zone provided by the R&D alliance in the single market situation and at this point, firm $W$ will encounter

Figure 3.3: Changes in market entry barrier due to multi-market linkage




(a) In single market

(b) In multi-market

vertical foreclosure anyhow. However, this point is located in the feasible zone in the presence of multi-market linkage, suggesting that firm $W$ can enter through the R&D alliance. The improvement in the R&D alliance's effectiveness comes from the incremental production in the relevant market that enhances firm $A$'s upstream profit.

## 3.5 Concluding remarks

This paper studies how an R&D alliance where an innovative downstream entrant licenses its technology to a vertically integrated upstream monopolist impacts vertical foreclosure, when firms face market reshuffling caused by the product update and the entrant cannot provide enough enforceable financial compensation to the upstream monopolist. The results suggest the significant yet limited effects of the R&D alliance on alleviating vertical foreclosure, as the alliance can help mitigate vertical foreclosure given a modest efficiency advantage of the upstream monopolist and a high survival probability of the alliance partners. The effectiveness of the R&D alliance in eliminating vertical foreclosure is challenged by backward spillovers in the supply chain yet it is still significant in this case. Multi-market linkage will reinforce the effectiveness of the R&D alliance on stimulating market entry.

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# Conclusion

In the wave of global trade openness, processing trade is still a privileged avenue to participate in Global Value Chains (GVCs) for firms in emerging economies like China, Mexico, and Vietnam, etc. Given this, there needs to be clarification as to how firms can optimize performance and maximize their positive impacts on the national economy in the pursuit of processing trade.

We employ the production data and customs data of Chinese manufacturing firms which are representative of firms' participation in processing trade to provide new stylized facts on this question. We investigate differences in performance including profitability, productivity, and processing export performance distinguishing firms with respect to the share of processing trade. In particular, we assess whether the performance of processing firms which also report ordinary trade flows (hybrid) differs from the performance of exporters exclusively involved in processing trade. We find that compared to purely processing firms, hybrid exporters report better outcomes in productivity, revenue, value added, and profit, as well as in the processing export performance when shipping the same products to the same single destination market.

Our results show that hybrid exporters replacing more imported inputs with domestic inputs in the processing production are associated with better performance, as they can benefit from the productivity progress of domestic input suppliers motivated by more inflow FDI and input tariff reductions. Previous studies showed that the input tariff exemptions and the income tax benefits granted to firms engaged in processing trade weaken these firms' innovation incentives, which explains their worse performance compared to ordinary exporters. Whereas our findings suggest that among processing firms, those which are able to access domestic inputs can report better performance.

Hybrid firms also export processed goods of higher quality as they tend to be more specialized: they supply a lower number of different products to the different international markets than purely processing firms. Our study thus demonstrates the significant differences between the performance of exporters of processing trade and provides the revelatory for firms on how to improve achievements by catching the bonus of trade openness.

However, along with the development of firms in emerging economies and their pursuit for independent innovation and national brands, foreign firms in developed economies are likely to control international knowledge diffusion brought by processing trade. We consider the competition and cooperation between the firm in a developed country and Chinese firms and explain the above logic with an outsourcing model incorporating technology spillovers.

We distinguish spillovers from processing trade on processing firms (the intra-firm channel) from those on domestic non-processing firms (the inter-firm channel). We further classify inter-firm spillovers into horizontal spillovers and backward spillovers. We find significant and positive spillovers on processing firms' productivity and the varieties of ordinary exports. However, the productivity spillovers are only significant in the short run, and the spillovers on product varieties eventually remain at a stable level, implying the upper limit of knowledge diffusion from processing trade.

We also find positive horizontal productivity spillovers on domestic ordinary exporters and negative backward productivity spillovers on domestic non-exporting firms in the base year (2002). The two sorts of spillovers subsequently decrease in scale, for which the investigation of possible mechanisms suggests different driving forces. We find that processing exporters spread production and product knowledge and generate diverse demands for inputs, steering domestic upstream non-exporting firms toward product development rather than productivity improvement. The interference with productivity is relieved by the gradual technology enhancement of domestic non-exporting firms. We do not find evidence supportive of more innovation activities of domestic ordinary exporters having reduced their productivity gains from horizontal spillovers. The lessening trend of this sort of spillovers is hence associated with external causes such as controls over spillovers.

This research has important policy implications. The mutual constraints between the continuous expansion of Chinese firms' technological frontier and spillovers from processing trade indicate that the new normal of the contribution of processing trade to China's technological progress began to take shape before 2007. In the face of such challenges, emerging economies, like China, must focus on developing innovation-driven strategies and seeking new economic growth engines.

Market entry is the premise of optimizing performance and thus another closely related issue for firms. The extant studies have shown that competitive market environments tend to contribute to economic growth and social welfare, which could, however, be deteriorated by entry barriers posed by rivals in international markets, such as vertical foreclosure. Taking into account that R&D alliances are becoming a more common path for seeking cooperation, the technology flows between partners, which serve as intangible asset compensations, seem to have the potential to facilitate market entry.

We thus consider the role of an R&D alliance between a vertically integrated upstream monopolist and an innovative downstream entrant in eliminating vertical foreclosure when firms face market reshuffling caused by the product update.

The entrant cannot provide sufficient financial compensations yet can license its technology to the upstream monopolist under an alliance and improve the latter's survival possibility. We find the positive yet limited effects of the R&D alliance on reducing vertical foreclosure. The effectiveness of the alliance is significant in the case of a modest efficiency advantage of the vertically integrated upstream monopolist and a high joint survival probability provided by the alliance, and will be reinforced by linked multiple downstream markets yet challenged by backward spillovers in the supply chain. Since in the latter case, the upstream monopolist can improve its survival prospect by learning via supplying the more innovative external downstream incumbent.

Our study conveys a couple of strong policy implications. R&D alliances can play a role in addressing vertical foreclosure, however, the application of this strategy needs to condition on specific market structures. Moreover, if upstream industry giants controlling one or several necessary inputs pay only little for appropriating backward spillovers, innovative downstream startups possessing superior knowledge may face more severe entry restraints. Therefore, enforceable policies aimed at vertical restraints are more fundamental in industries facing significant spillovers occurring in vertical linkages.

## Eidesstattliche Versicherung

Ich, Frau Xiaodong Bie, versichere an Eides statt, dass die vorliegende Dissertation von mir selbstständig und ohne unzulässige fremde Hilfe unter Beachtung der „Grundsätze zur Sicherung guter wissenschaftlicher Praxis an der Heinrich-Heine-Universität Düsseldorf“ erstellt worden ist.

Düsseldorf, der 26. September 2021