Structure and Behavior of Multi-product Firms: Evidence from India

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1. Introduction

A central theme of international trade research has been the impact of trade liberalization on productivity. Work by Prescott (1998), Pavnick (2003), Amity and Konings (2007), and Feenstra and Kee (2008) argue that differences in productivity mostly explain the income differences across countries, that trade liberalization improves productivity, and that all economic agents share the gains from productivity following trade liberalization.

Early literature on this theme points out that trade liberalization brings resource/organizational adjustment across industries and this adjustment enhances productivity. A traditional comparative advantage or monopolistic competition model examines responses at the average, i.e. homogeneous firms. In recent years, heterogeneous firm models with a general equilibrium framework expand the debate to include organizational adjustment across firms. Following trade liberalization, more efficient industries or firms expand their production and attain exporting status while inefficient industries or firms shrink or even leave the market. The heterogeneous firm models argue that there is organizational adjustment across firms even within an efficient industry. Contributions by Melitz (2003), Bernard and Jensen (2004), Melitz and Ottaviano (2008), and Bernard, Redding, and Schott (2007), argue that only firms with productivity levels higher than a certain cutoff self select to serve domestic and foreign markets. The productivity improvement in the heterogeneous-firms framework arises through organizational adjustments of industries or firms following trade liberalization. The exit of less efficient

[1] The views expressed here are those of the authors, and may not be attributed to the Economic Research Service or the U.S. Department of Agriculture.

industries or firms and the transfer of their resources to more efficient industries or firms lead to improvements in industry or national productivity.

A new strand of the heterogeneous firm literature is now considering explanations of productivity change arising from intra-firm resource reallocation in the presence of product heterogeneity. Under firm heterogeneity, a firm's technology uses determine their productivity; technology usages include technologies adoption and efficient use of adopted technologies. However, recent literature points out that there is a possibility that intra-firm resource reallocation affect a firm's productivity in addition to technology usages. Restuccia and Rogerson (2013) summarize direct and indirect approaches explaining the impact of intra-firm resource reallocation on a firm's total factor productivity (TFP). The direct approach directly employs multiple factors affecting TFP, and measures the magnitude of each factor's impact on TFP. In contrast, the indirect approach does not explicitly select factors, but it measures the aggregated effect of all causal factors on TFP. Work by Eckel and Neary (2010), Bernard, Redding, and Schott (2011), and Mayer, Melitz and Ottaviano (2011) show that product heterogeneity drives intra-firm resource allocation. Product heterogeneity can consist of either productivity differences across products (Eckel and Neary, 2010; Mayer, Melitz and Ottaviano, 2011) or differences in attributes across products (Bernard, Redding, and Schott, 2011). Attribute differences refer to that products are symmetric in terms of productivity, but differ in terms of characteristics such as brand and quality. These studies claim that as firms change their number of products, it also changes firm-level productivity because changes in the number of products cause inefficient management or lead allocation of inputs to less efficient products. In addition to technology adoption and usage, intra-firm resource reallocation can determine attained productivity in addition to technology uses.

The purpose of this study is to show whether intra-firm resource reallocation affects multi-product firms' TFP. Intra-firm resource reallocation is made up of two components: the number of products a firm produces (product range), and the way a firm allocates input resource across products (skewness of production). For this study, TFP is measured using De Loecker's (2011) approach adopting the Cobb-Douglas production and CES utility functions under multi-product firms and applying two-stage estimation procedure. An appealing feature of De Loecker's (2011) approach is that unobserved price effects are controlled for when a revenue-production function is estimated using deflated revenue instead of quantity. The revenue-production function requires the assumption that price effects in revenue are eliminated by deflating them with industry wide producer price index. However, if unobserved price effects are not eliminated through deflation, it might cause omitted price variable problem due to correlation between output price and input use. Alternatively, De Loecker (2011) suggested that unobserved price effects can be controlled by combining a production function with a demand function. In addition, this study modifies De Loecker's (2011) model to consider the internalized demand linkage of multi-product firms.

The intra-firm resource reallocation and productivity link is examined through the testing of two hypotheses: (i) high productivity firms have larger revenue and larger product range than low productivity firms and (ii) discontinuing a product and (/or) skewing production toward a particular product increases TFP while adding a product and (/or) equalizing the production of all products decreases TFP.

These hypotheses have three implications. First, TFP is positively correlated with both revenue and product range. However expanding product range decreases TFP due to increasing possibility of input resource misallocation. Second, a firm's TFP depends not only on technology usages, but also on intra-firm resource reallocation. The product range and he way to allocate input resource across heterogeneous products also affect a firm's TFP. In other words, aggregate TFP depends not only on organizational adjustment across industries or firms, but also on organizational adjustment within a firm.

Finally, getting export status significantly increases multi-product firms' productivity due to the relationship between intra-firm resource reallocation and productivity.

For the empirical analysis, the production and finance accounts of the PROWESS database on Indian firms (31,100 firms with 213,134 observations; 3,844 products with 213,134 observations) are used. This unique database allows the study to focus on multi-product firms' structure, productivity, product range, and skewness of production.

The remainder of this study is organized as follows. The next section describes the empirical models. Section 3 contains estimation strategies, while section 4 introduces the data and Section 5 discusses hypotheses and results. The last section concludes.

2. Empirical Model

As noted earlier, multi-product firms' productivity is estimated using the De Loecker's (2011) approach. However, this study considers an additional effect in the TFP estimation: cannibalization. If a firm changes its product range or (/and) skewness of production, physical outputs of products within a firm and prices are affected. In addition, following the assumptions in Bernard, Redding, and Schott (2011), this study uses a model where all products within a firm possess identical productivity, but they are heterogeneous in terms of attributes such as quality and brand names. A product' physical output is affected by a firm's productivity, but price of each product is different due to heterogeneous attributes. This approach is analytically tractable and can be readily tested using firm- and product-level data.

2.1. PRODUCTION

A product' production is a function of technology and a firm's productivity. Homogeneous technology and common input prices across products are assumed. Autarky is assumed as well. Product *i* of firm *j* has a standard Cobb-Douglas production function, given by

$$(1)\ Q_{it}^{j} = \left(a_{it}^{j} L_t^{j}\right)^{\alpha_l} \left(a_{it}^{j} M_t^{j}\right)^{\alpha_m} \left(a_{it}^{j} K_t^{j}\right)^{\alpha_k} exp\left(\varphi_t^{j}\right)$$

$$= \left(a_{it}^{j}\right) Q_t^{j}$$

where $i \in I_j(i)$ and $I_j(i)$ is a set of products in firm *j*; Q_{it}^{j} denotes physical output of product *i* in firm *j* at time *t*; Q_t^{j} denotes firm *j*'s aggregated physical output; L_t^{j}, M_t^{j}, and K_t^{j}, are labor, material, and capital, respectively; φ_t^{j} denotes multi-product firms' unobservable productivity; a_{it}^{j} denotes input share of product *i* in firm *j*'s input uses and shows how much inputs are allocated to product *i*; and $\sum_{i \in I_j(i)} a_{it}^{j} = 1$ and $a_{hit}^{j} = a_{it}^{j}$ for $\text{h} = \{L_t^{j}, M_t^{j}, K_t^{j}\}$. The assumptions for input share imply that the production function satisfies input proportionality and that there is no input cost synergy[2]. Technology satisfies Constant Returns to Scale (CRS), $\alpha_l + \alpha_m + \alpha_k = 1$.

A firm's aggregated physical output is the sum of the multiple products' output, given by,

$$(2)\ Q_t^{j} = \sum_i Q_{it}^{j} = \sum_i \left(a_{it}^{j}\right) Q_t^{j} = \left(L_t^{j}\right)^{\alpha_l} \left(M_t^{j}\right)^{\alpha_m} \left(K_t^{j}\right)^{\alpha_k} exp\left(\varphi_t^{j}\right)$$

Physical output is not available due to data constraints. In general, deflated revenue by the producer price index is used with the assumption that unobserved price effects in revenue are eliminated by deflating it. However, uncontrolled price effects in revenue cause omitted price variable problem if omitted prices are correlated with input uses. Alternatively, De Loecker (2011) suggest that by combining Cobb-Douglas production function with CES preference, unobserved price effects in revenue can be controlled for.

[2] De Loecker (2011) noted that the only case violating input proportionality is a firm activating multi-sections, and potentially faces different demand elasticity. With input proportionality, firms spread their inputs equally over each unit of output, so long as the marginal revenue of one unit of output is equals marginal cost. However, if a firm produces and sells its products in different sections, and each section has different demand elasticity, then the firm would not equally allocate its resource. In order to verify this, De Loecker implements a sensitivity analysis by estimating without multi-section firms and obtains consistent results supporting input proportionality.

2.2. DEMAND

All consumers have a common utility function satisfying Constant Elasticity Substitution (CES) preference. Consumers' demand on product *i* from firm *j* is given by,

$$(3)\ Q_{it}^{j} = Q_{st}\left(\frac{P_{it}^{j}}{P_{st}}\right)^{\sigma_s} exp\left(\xi_t^j\right) \quad .$$

where σ_s denotes elasticity of substitution and it is allowed to vary by section *s*, $-1 < \sigma_s < 0$; Q_{st} denotes total demand of section *s*'; P_{it}^{j} denotes price of product *i* from firm *j*; P_{st} denotes price index of section *s*; ξ_t^j denotes firm specific unobserved demand shocks. CES preference implies constant markups over margin costs.

2.3. AGGREGATION

Firm *j*'s aggregated revenue is given by $\mathrm{R}_t^j = \sum_i \mathrm{P}_{it}^j \mathrm{Q}_{it}^j$. By combing the production and the demand functions, firm *j*'s revenue function is given by,

$$(4)\ R_t^j = A_t^j P_{st} Q_{st}^{-\frac{1}{\sigma_s}} \left(L_t^j\right)^{\left(\frac{\sigma_s+1}{\sigma_s}\right)\alpha_l} \left(M_t^j\right)^{\left(\frac{\sigma_s+1}{\sigma_s}\right)\alpha_m} \left(K_t^j\right)^{\left(\frac{\sigma_s+1}{\sigma_s}\right)\alpha_k} \left(exp\left(\xi_t^j\right)\right)^{-\frac{1}{\sigma_s}} \left(ex\,p\left(\varphi_t^j\right)\right)^{\frac{\sigma_s+1}{\sigma_s}}$$

where A_t^j denotes firm *j*'s input index which is the sum of a product *i*'s input share powered by the elasticity of substitution, $A_t^j = \sum_i \left(a_{it}^j\right)^{\frac{\sigma_s+1}{\sigma_s}}$. The input index reveals how to allocate input resource across products. In this study, the input index is adopted as a skewness of production to measure intra-firm resource reallocation.

By taking logs, equation (4) can be written as the following,

$$(5)\ r_t^j = p_{st} + a_t^j + \left(\frac{\sigma_s+1}{\sigma_s}\right)\alpha_l\, l_t^j + \left(\frac{\sigma_s+1}{\sigma_s}\right)\alpha_m\, m_t^j + \left(\frac{\sigma_s+1}{\sigma_s}\right)\alpha_k\, k_t^j - \frac{1}{\sigma_s}q_{st} - \frac{1}{\sigma_s}\xi_t^j + \frac{\sigma_s+1}{\sigma_s}\varphi_t^j$$

where lower cases denote logs. Estimable equation is given by,

$$(6)\ \tilde{r}_t^j = \beta_A a_t^j + \beta_l l_t^j + \beta_m m_t^j + \beta_k k_t^j + \sum_s s_s^j\, \beta_q q_{st} + \varphi_t^{j^*} + \xi_t^{j^*} + \upsilon_t^j$$

where $\tilde{r}_t^j$ is deflated revenue by producer price index in industry s, $\tilde{r}_t^j \equiv r_t^j - p_{st}$; s_s^j denotes dummies for multi-section firms. $s_s^j = 1$ if a firm serves that section. Otherwise, it is zero; $\beta_h = \frac{\sigma_s+1}{\sigma_s}\alpha_h$ for $h = \{l,\ m,\ k\}$; $\beta_q = \frac{1}{|\sigma_s|}$; $\varphi_t^{j*} \equiv \varphi_t^j\left(\frac{\sigma_s+1}{\sigma_s}\right)$; $\xi_t^{j*} \equiv \xi_t^j|\sigma_s|^{-1}$; and v_t^j denotes residuals and are stochastic *i.i.d.* over firms and time.

3. Estimation Strategy

3.1. Estimation Strategy for production function

Unobserved demand shocks, ξ_t^j, in equation (6) are decomposed into observable nesting structures of the product data and the product range, n_j^t, and the stochastic component, $\tilde{\xi}_t^j$, as the following[3],

(7) $\xi_t^j = \sum_{i \in J(i)} D_{it}^j + \sum_{g \in G(i)} D_{it}^j + n_t^j + \tilde{\xi}_t^j$

where D_{it}^j and $D_{g_i t}^j$ denotes dummies for product and product-group[4]. The set of products is $J(i)$; stochastic components are *i.i.d.* across firms and time. Product range of firms has an impact on demand shocks due to the cannibalization effect, where output or market share of one product can be changed as a result of introduction of a new product by an identical firm. The cannibalization effect captures internalized demand linkages of multi-product firms (Eckel and Neary, 2010)[5]. Decomposing demand shocks by nesting the structures of products is examined by Goldberg (1995) and De Loecker (2011). Note that if the assumption that production function is common across products is not satisfied, then dummies for products could capture the difference in production technology.

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[3] Nesting structures of the product data includes product (5 digit SITC), product-group (3 digit SITC), industry (2 digit SITC) and section (1 digit SITC). All these nesting structures could be included in estimation, but by doing so, it brings other problems. It significantly reduces the efficiency of estimation and it is also complicated to implement estimation due to limitation of static program. This study only considers product as a nesting structure of product and the data also supports this in a way that group effects of product-group, industry and section are insignificant.

[4] SITC is categorized by Section (1 digit SITC), Industry (2 digit SITC), Product-group (3 digit SITC), and Product (5 digit SITC). In SITC, there are 10 Sections, 67 Industries, 262 Product-groups, and 2970 Products.

[5] Loecker (2011) decomposes demand shocks by nesting structure of product data and protection rate in trade because changes in protection rate affects price of a product and so demand of it.

A multi-product firm's productivity determination process is defined as a function of past productivity, past product range, past skewness of production, intersection of past product range and past skewness of production, and stochastic components, η_t^j, as given by[6],

(8) $\varphi_t^j = g_t(\varphi_{t-1}^j,\ a_{t-1}^j,\ n_{t-1}^j, a_{t-1}^j n_{t-1}^j\ ) + \eta_t^j$

where stochastic components, η_t^j, are interpreted as innovation and *i.i.d* across producers and time[7]. The adoption of efficient technologies and efficient use of adopted technologies determine a firm's potential TFP which is the maximum level of TFP a firm can achieve. For reference, Bernard, Redding, and Schott (2011) show that by adding or dropping a low-attribute or a less-attractive product(s), multi-product firms' TFP is affected; this is based on the assumption that all products within a firm have the same productivity but are different in terms of attributes and attractiveness such as brand names, brands' age, and quality. Changes in TFP occur because changes in product range lead organizational adjustments within a firm.[8]

Product range and skewness of production in equation (8) capture the relationship between intra-firm resource reallocation and TFP. If a firm efficiently allocates resources across products, potential TFP is achieved. However, multi-product firms frequently change their product range and skewness of

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[6] Loecker (2011) identifies the law of motion on productivity is a function of past productivity and protection rate.

[7] $\eta_t^j = \varphi_t^j - g_t(\varphi_{t-1}^j,\ n_{t-1}^j,\ A_{t-1}^j)$ and so it is interpreted as innovation.

[8] Bernard, Redding, and Schott (2011) assume that product heterogeneity comes from demand side, not from production side. Products within a firm have different attributes or attractiveness, and so their demand levels are different. According to this product heterogeneity, firms determine their production strategy. The different approach on product heterogeneity are Eckel and Neary (2010) and Mayer, Melitz and Ottaviano (2011). They assume that products are heterogeneous in terms of productivity which is reflected in different marginal cost. Eckel and Neary (2010) assume that multi-product firms tend to have core competence in the production of a particular product(s) within a firm and that they are less efficient in the production of products outside of their core competence. Multi-product firms expand their product range to have additional profit from a newly adding product, but they have to take inefficiency from the new product due to their core competence. As a result, a firm's productivity decreases as they expand their product range. However, how much inefficiency a firm has to take depends on firm's ability or productivity. In the same manner, Mayer, Melitz, and Ottaviano (2011) assume that multi-product firms' productivity decrease at a constant rate proportional to the firms' initial productivity as the firm expands its product range. They show that as a firm reallocates their resources toward the least efficient product within a firm, multi-product firms' productivity decreases.

production to maximize profit. As a firm frequently changes intra-firm resource reallocation, the possibility of misallocating resources increases which reduces TFP.

The law of motion on productivity implies that intra-firm resource reallocation affects multi-product firms' TFP, and that firms need some time to reorganize management and production systems across products without affecting input use, as well as to eliminate inefficiency. Thus previous intra-firm resource reallocation affects current productivity.

Shocks in demand and productivity lead to the main estimable equation as the following,

$$(9)\ \tilde{r}_t^j = \beta_k k_t^j + \beta_l l_t^j + \beta_m m_t^j + \beta_a a_t^j + \beta_n n_t^j + \beta_{sq} q_{st} + \delta_p D_{pt} + \delta_{pg} D_{pgt} + \delta_y D_y + \varphi_t^{j^*} + \upsilon_t^{j^*}$$

where D_{pt}, D_{pgt}, and D_y denote dummies for products, product-groups and year, respectively; $\upsilon_t^{j^*}$ denotes stochastic demand shocks and residuals, $\upsilon_t^{j^*} \equiv \tilde{\xi}_t^j + \upsilon_t^j$; β_{sq} denotes a combination of a set of dummies for sections and coefficients, $s_s^j \beta_q$. However, equation (9) is not directly estimated due to the input index and correlation between unobserved productivity and inputs.

The input index, a_t^j, is not directly observable because the data showing a product's input use is not available. As a proxy for a product's input use, a product' revenue share is used. If a firm allocates large portions of inputs to a particular product, the output of that product would be larger than any other product within a firm. In the same manner, the revenue of the falls under the assumption that input prices are common across products, and that mark-ups are constant over marginal costs as in CES preference. As an instrument for input index, the Herfindhal Index of revenue by product, $h_t^j = \sum_i \left(\frac{r_{it}^j}{\sum_i r_{it}^j} \right)^2$, is used as a mean to capture the degree of concentration in production over products within a firm. The Herfindhal index has the same feature with the input index that it has the highest value if a firm equally allocation its inputs across products and the index increases as a firm skews its inputs toward a particular product. Products' revenue are used to calculate the Herfindhal index.

Estimating equation (9) through Least Squares would yield biased results because of correlation between unobserved productivity and labor, and strong collinearity between labor and other inputs. Labor is regarded as a freely adjustable input. Firms are more likely to change labor when they have unexpected productivity shocks because of free adjustability. This leads to an omitted variable problem if this correlation is not controlled. In addition, labor could be a deterministic function of capital and material when the production function is estimated in a Cobb-Douglas function. Ackerberg, Caves, and Frazer (2006) show that there could be an identification problem pertaining labor, and even worse, labor drops out when the production function is in Cobb-Douglas form.

Basically, this study estimates equation (9) through a two-stage-procedure to deal with correlation and the collinearity problems which is introduced by De Loecker (2011). In the first stage, material is used as a proxy for unobserved productivity and is given by,[9]

(10) $m_t^j = m_t\left(k_t^j, \varphi_t^j, a_t^j, n_t^j, q_{st}, D_{pt}\right)$.

Material demand is monotonically correlated with unobserved productivity (Levinsohn and Petrin (2003); De Loecker (2011)). By inverting the material demand function, a function, $h_t(\cdot)$, is defined as,

(11) $\varphi_t^j = h_t^j\left(k_t^j, m_t^j, a_t^j, n_t^j, q_{st}, D_{pt}\right)$.

The main estimable equation is rewritten as the following,

(12) $\tilde{r}_t^j = \delta_{pgt} D_y + \delta_y D_y + \Lambda_t^j(X_1, X_2) + \upsilon_t^{j^*}$

where

(13) $\Lambda_t^j(X_1, X_2) = X_1\left(k_t^j, l_t^j, m_t^j, a_t^j, h_t^j(\cdot)\right) + X_2\left(n_t^j,\ q_{st},\ D_{pt}\right)$

$X_1(\cdot)$ includes all input variables and $X_2(\cdot)$ includes all demand variables. The non-linear term,

9 Investment can be considered as a proxy for unobserved productivity as well. However, data constraints restrict the use of investment as the proxy for productivity. Data has significant number of firms report zero investment.

$\Lambda_t^j(X_1, X_2)$, in equation (12) is approximated by fourth-order polynomials,

(14) $\Lambda_t^j(\cdot) = \sum_{a=0}^{3}\sum_{b=0}^{3-b} \omega_{ab} \left(X_1(\cdot)\right)^a \left(X_2(\cdot)\right)^b$.

Note that interaction terms with product dummies are not considered due to the limitation of a static program. With polynomial approximation, equation (12) is estimated through OLS and unbiased estimates of dummies for product-group and year are estimated. In equation (12), material is used as a proxy for unobserved productivity. Next the fitted value of the non-linear term, $\widehat{\Lambda_t^J(\cdot)}$, is calculated as in the following,

(15) $\widehat{\Lambda_t^J(\cdot)} = \widehat{\tilde{r}_t^J} - \widehat{\delta_{pgt}} D_y - \widehat{\delta_y} D_y$

Note that the fitted value does not include the residual, $\upsilon_t^{j^*}$.

Unbiased productivity can be calculated with unbiased coefficients of inputs as the following,

(16) $\varphi_t^{j^*}(\beta_k, \beta_m, \beta_a, \beta_n, \beta_{sq}, \delta)$

$= \widehat{\Lambda_t^J(\cdot)} - \beta_k{}^* k_t^j - \beta_l{}^* l_t^j - \beta_m{}^* m_t^j - \beta_a{}^* a_t^j - \beta_n{}^* n_t^j - \delta_p^* D_{pt}$.

where $\beta_k{}^*,\ \beta_l{}^*,\ \beta_m{}^*,\ \beta_a{}^*,\ \beta_n{}^*, and\ \delta_p^*$ are unbiased estimates of inputs and demand variables. The law of motion on productivity is estimated using the calculated unobserved productivity from equation (16),

(17) $\widehat{\varphi_t^{J^*}} = \beta_1\ \widehat{\varphi_{t-1}^J} + \beta_2 a_{t-1}^j + \beta_3 n_{t-1}^j + \beta_4 a_{t-1}^j n_{t-1}^j + \eta_t^j$

Next, the fitted value of productivity $\widehat{\widehat{\varphi_t^{J^*}}}$ is calculated[10]. The stochasitic *i.i.d.* component which is interpreted as innovation, $(\widehat{\eta_t^J})$, is calculated as in the following,

(18) $\widehat{\eta_t^J} = \widehat{\widehat{\varphi_t^{J^*}}} - \widehat{\beta_1}\ \widehat{\widehat{\varphi_{t-1}^J}} - \widehat{\beta_2} n_{t-1}^j - \widehat{\beta_3} a_{t-1}^j - \widehat{\beta_4} a_{t-1}^j n_{t-1}^j$

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[10] As in equation (18), the *i.i.d.* components are dropped.

All coefficients of inputs can be calculated using the moment condition. The moment equation can be used as such,

$$(19)\quad \mathrm{E}\left\{\left(\eta_t^j\left(\beta_k^{\ *},\ \beta_l^{\ *},\beta_m^{\ *},\beta_a^{\ *},\ \beta_n^{\ *},\ \widehat{\beta_{sq}}\ ,\delta_p^*\right)\right)\begin{pmatrix} k_t^j \\ l_{t-1}^j \\ m_{t-1}^j \\ a_{t-1}^j \\ n_{t-1}^j \\ q_{st} \\ \mathrm{D}_{pt} \end{pmatrix}\right\} = 0$$

where variables for freely adjustable inputs and intra-firm resource reallocations are lagged due to correlation between innovation, η_t^j, and those inputs. Let estimated coefficients be $\widehat{\beta_k}$, $\widehat{\beta_m}$, $\widehat{\beta_a}$, $\widehat{\beta_n}$, $\widehat{\beta_{sq}}$ and $\widehat{\delta_p}$.

3.2. Estimation Strategy for Multi-product Firms' TFP

The original unobserved productivity shocks can be recovered by,

$$(20)\quad \widehat{\varphi_t^j} = \left(\tilde{r}_t^j - \widehat{\beta_l} l_t^j - \widehat{\beta_k}\, k_t^j - \widehat{\beta_m}\, m_{t-1}^j - \widehat{\beta_a}\, a_{t-1}^j - \widehat{\beta_n}\, n_{t-1}^j - \widehat{\beta_{sq}}\, q_{st} - \hat{\delta}_p\, D_{pt} - \hat{\delta}_y\, D_y\right)\left(\frac{\sigma_s}{1+\sigma_s}\right)$$

where σ_s is obtained by $\sigma_s = \frac{1}{|\beta_{sq}|}$; As for multi-product firms, the shares of physical output in section *s* are used as a weigh $\sum_s \left(\frac{\sigma_s}{1+\sigma_s}\right)\frac{\widehat{\beta_{sq}}\, q_{st}}{\sum_s \widehat{\beta_{sq}}\, q_{st}}$, instead of $\left(\frac{\sigma_s}{1+\sigma_s}\right)$.

4. DATA

This study uses the PROWESS database (PROWESS) on Indian firms over the 1989 – 2009 periods. These data have been collected by the Centre for Monitoring the Indian Economy (CMIE), and show the production and financial performance of companies in India from 1988 to present. As per the Companies Act in 1956, all Indian business entities are required to report production and financial information. CMIE has been collecting this information using its own classifying system for product and industry

(PROWESS code). Goldberg et al. (2009, 2010a, 2010b), Topalova and Khandelwal (2011), and Loecker et al. (2012) use this data in their analysis as well.

The advantage of PROWESS is the availability of product-level revenue by firm. The history of the product range and skewness of production can be tracked from 1989 to 2009 periods. The disadvantage is that PROWESS is not a comprehensive database and covers mid- and large- size companies in the organized sector. However, this database includes firms and products accounting for 60-70% of total economic activity in India. Although small firms are not included in the PROWESS, this study focuses on intra-firm resource reallocation on productivity. Most small firms are likely to single-product firms and thus, intra-firm resource reallocation across products may not be a relevant issue.

PROWESS defines product by a 20-digit PROWESS code and firms by name. This study manually converts PROWESS code to 5 digit Standard International Trade Classification (SITC) code. Note that other existing literature using PROWESS converted it to Indian National Industrial Specification code. The hierarchical structure of industrial classification is as follows product is defined by 5-digits in SITC coding. Within a product category, multiple brand names can be included. Even though a firm frequently changes a brand name, the product that belonged to a brand is continually produced without any change in its status (Baldwin and Harrigan, 2011). Product-group is defined by 3- digits in SITC coding. Product-group includes most products using identical raw materials. Industry is defined by 2-digit digits in SITC coding and Section is defined by 1-digit in SITC coding. SITC code classifies 2,970 products, 1,023 product-groups, 67 industries, and 10 sections.

The original PROWESS covers all industries including the service industry, but this study does not include service industry. Observations in 1988 and 2010 are dropped as well because observations from those years are not enough in terms of observation and consistency to observations in next year. 1988 is the first year and 2010 is the latest year of the data collection. In addition, all firms having the inconsistent accounting year problem are dropped with the exception of firms with financial accounting years. In PROWESS, 80% of firms in PROWESS follow the financial year from April of the accounting year to March of the following year, 15% of firms follow the calendar year from January to December of the accounting year. Most foreign firms use the calendar year. After aggregating the original database by the hierarchy structure of industrial classification, there are 61,823 observations, but 6,707 (10.8%) observations are missing. These missing years are filled with previous values. All statistics in this study include filled values.

Based on the availability of data for Indian firms, this study works with 61,823 observations (by taking lagged value, 6,891 observations are dropped) across 6,891 firms, 1,395 products, 253 product-groups, 63 industries, and 9 sections. This study measures the intra-firm resource allocation by product range and skewness of production.

Table I illustrates the variation in revenue, capital, labor, material, skewness of production, and product range across 61,823 observations, 6,891 firms, and an average of 8.97 producing years per firm from 1989 to 2009 periods. Considerable temporal variation is visible in these data: between-year standard deviations of all variables are greater than 1.50, except for skewness of production. However, the skewness of production ranges from 0 to 1, so, it varies considerably as well. This table highlights the dramatic growth of Indian firms. Within-year standard deviations show the extent of firm heterogeneity in the data.

Table II reports the number of firms, average product range, and average skewness of production by time. The share of single-product firms is increasing during the sample period. In 1989, the share of single product firms is 46.2%, but it is 59.0% in 2009. Note that the share of single-product firms is relatively smaller than that in the United States. For example, Bernard, Redding, and Schott reported that the share of single-product firms is 61% during 1987 to 1997 in U.S. The average product range is decreasing, but the average skewness of production is increasing during the sample period. Regardless of the inclusion of single-product firms, the trend in both variables is identical. This highlights specialization of Indian firms' production toward particular products. Work by Melitz (2003), Mayer, Melitz, and Ottaviano (2011), and Bernard, Redding, and Schott (2011) pointed out that firms tend to reallocate their resource toward particular products in response to intensifying competition following trade liberalization.

Table III and IV summarize the share of firms by changes in product range and skewness of production. On average, 12.1% firms change their product range, and 24.0% firms change their skewness of production during the sample period. This means that firms are more likely to change their skewness of production than product range.

Table V shows the correlation between product range and skewness of production. Mayer, Melitz, and Ottaviano (2011), and Bernard, Redding, and Schott (2011) did not distinguish these two variables explicitly because they show identical information. The VIF between product range and skewness of production is 2.0 which is smaller than 5; the R-square is 0.52, and the correlation coefficient is -0.72. These two variables are negatively correlated, but one variable only explains the half of the other variable.

5. Results

This section reports on the testing of the two hypotheses about the structure and behavior of multi-product firms. First, the estimation and results of the Cobb-Douglas production with CES preference is outlined. Then, calculated (unobserved) TFP from estimating the production function is discussed. Next, this section examines the relationship between TFP and revenue, skewness of production, and product range. Finally, the link between intra-firm resource reallocation and multi-product firm's TFP is estimated. Those hypotheses, as noted earlier, are drawn from work by Bernard, Redding, and Schott (2011), and Mayer, Melitz, and Ottaviano (2011).

5.1. Production Function

The Cobb-Douglas production function with CES preference in equation (9) is specified with the following variables: revenue, capital, material inputs (deflated by GDP deflator), real interest rate, and energy price index. For each firm, (sections') demand is calculated by summing products' deflated revenue by section. As noted earlier, product range is measured by counting products within a firm by 5-digit SITC, and skewness of production is measured by the Herfindhal index of product's revenue.

Table VI reports regression results of deflated revenue on capital, labor, material, skewness of production, product range, interaction of skewness of production and product range, sections' demands, and fixed effect terms for product and year, with all variables in logs except fixed effect terms. As column (1) shows, revenue increases with capital, labor, material, skewness of production, product range and sections' demand, and all coefficients are significant at 1%. In the regression, the constraint for CRS is not applied, but sum of coefficient is 1.0293 which is statistically identical with unity. It also shows that internalized demand linkage of multi-product firms plays a significant role in estimating the revenue-production function. Expanding product range and skewing production increase a multi-product firm's revenue, but product range has larger effect than skewness of production. The elasticity of product range with respect to revenue is 0.2696 which is three and a half times larger than that of skewness of production. Note that expanding product range could take demand away from the existing product(s) within a firm due to cannibalization effects. However, if consumers' recognition to the firm is sufficiently favorable, then expanding product range ultimately leads increase in aggregate revenue.

Columns labeled (2)-(4) show OLS results without and with lagged values, and 2SLS estimation methods, respectively. The difference between these three methods and De Loecker's approach is how to control the correlation between unobserved productivity and other dependent variables. In De Loecker's approach, the moment condition uses the independence between dependent variables and innovations in the law of motion on productivity. In contrast, OLS without lagged values ignores the correlation, but OLS with lagged and 2SLS control the correlation by using the independence between lagged dependent variables and unobserved productivity. Note that labor, material, skewness of production, product range, and interaction of skewness and product range are lagged. The law of motion on productivity in equation (8) shows that previous productivity affects both lagged dependent variables and unobserved productivity. Both variables are more likely to show co-movement which might cause correlation between dependent variables and unobserved productivity. Column labeled (2) and (4) show that coefficients of skewness of production and product range are insignificant. This is because the possible correlation between these two variables and unobserved productivity where correlation increase the standard errors of coefficients. Even though coefficient of product range in column (3) is negative and significant at 1%, but it also has correlation problem with unobserved productivity. In addition, De Loecker's approach does not include the interaction term of skewness of production and product range because the law of motion on productivity includes it.

5.2. Multi-product Firms' structure

This study next considers the multi-product firms' structure as in the following hypothesis I,

Hypothesis I. A firm having high productivity has larger revenue and product range than low productivity firms.

Bernard, Redding, and Schott (2011), and Mayer, Melitz, and Ottaviano (2011) predict the hierarchical structure across firms that high productivity firms earn higher revenue and have lager product range. Due to data constraint, firms' profit is not available. Instead, the TFP's relationship with revenue is tested. The following regressions explore how TFP explains heterogeneous revenue and product range across firms.

(21) $r_t^j = \beta_0 + \beta_1 \varphi_{t-1}^j + \upsilon_t^j$,

(22) $n_t^j = \beta_0 + \beta_1 \varphi_{t-1}^j + \upsilon_t^j$,

Note that TFP is calculated as residual after generating the production function.

Table VII illustrates that high TFP firms are more likely to make larger revenue which is consistent with hypothesis I. All values are in log. Adjusted R^2 is pretty small, 0.0024, but this is because the productivity is not a major driving factor of revenue.

Table VIII establishes contradicting results to hypothesis I that high productivity firms tend to have smaller product range. This means that high productivity firms are more likely to reduce their product range which is the opposite of Bernard, Redding, and Schott (2011), and Mayer, Melitz, and Ottaviano (2011). A possible explanation for this is the following. There are two ways to increase revenue. The first way is expanding product range to take additional revenue as noted earlier. The second way is reducing product range. The relationship between productivity and reducing product range is examined in the next section. However, if a firm productivity can be increased by reducing product range, and improved productivity from reducing product range leads to larger revenue gain than that from expanding product range, firms are more likely to reduce their product range as in the results in Table VIII.

5.3. Multi-product Firms' behavior

Next, this study explores the impact of intra-firm resource reallocation on TFP as in hypothesis II,

> ***Hypothesis II. Reducing product range and (/or) increasing skewness of production increase a firm's productivity, while expanding product range and (/or) decreasing skewness of production lower it.***

Consider the productivity determination process in equation (8). Table IX reports the regression results that only product range negatively affects productivity at 1% significant level, and skewness of production and interaction of skewness of production and product range do not. This means that by reducing product range, firms' productivity increase which supports the prediction in Bernard, Redding, and Schott (2011), and Mayer, Melitz, and Ottaviano (2011). However, magnitude of product range's coefficient is negligibly small.

These results are preliminary as the estimation work is ongoing. Revisions to results will occur as more firms and data are brought into the sample for estimation purposes.

6. Conclusion

This study examines the structure and behavior of multi-product firms by establishing two hypotheses using a rich database on Indian firms. In estimating TFP, the study finds that internalized demand linkage of multi-product firms plays a significant role in revenue under the assumption of a CRS Cobb-Douglas production function and CES consumer preference. When a firm expands its product range and skews its production toward a particular product(s), its revenue increases significantly. As for two hypotheses, we find that revenue increases with productivity, but product range decreases with it. Only product range has a negative effect on productivity, but it is negligibly small. However, skewness of production does not impact a firm's productivity.

The findings in this study have three main implications. First, TFP is the major source explaining different revenue, profit, product range, and production combination across firms. More successful firms produce more output. Second, firms' productivity does not depend only on a firm's technology usages, but also intra-firm resource reallocation. A firm has to sacrifice some of its productivity when it introduces a new product to take additional revenue or profit. The latter has implications for input resource misallocations in the emerging literature on product heterogeneity. Finally, multi-product firms' productivity could increase soon after receiving export status because they reallocate resources toward the new export product. Only some of the products within a firm are exported. Right after getting export status, firms may be limited in expanding capital in a short time to supply products to domestic and foreign markets, simultaneously. Thus, firms could reallocate their resource toward new export products and this also leads to intra-firm resource reallocation. Firms could increase skewness of production towards export products and even reduce product range to supply their products to domestic and foreign markets.

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7. Appendix (Tables)

TABLE I. The Variation in Revenue, Capital, Labor, Material, Skewness of Production, and Product Range

Variable		Mean	Std. Dev.	Min	Max	Observations
Revenue	overall	1.38	1.83	-6.52	10.18	N =61,823
	between		1.80	-6.52	8.94	n = 6,891
	within		0.64	-4.82	6.76	T-bar = 8.97
Capital	overall	5.78	1.69	-1.65	14.28	N =61,823
	between		1.61	-0.69	14.14	n =6,891
	within		0.61	0.41	10.46	T-bar = 8.97
Labor	overall	4.31	1.96	-2.25	12.35	N =61,823
	between		1.86	-1.98	12.03	n =6,891
	within		0.67	-1.95	8.04	T-bar = 8.97
Material	overall	-0.31	2.06	-8.24	8.33	N =61,823
	between		2.04	-8.24	7.10	n =6,891
	within		0.80	-10.74	4.85	T-bar = 8.97
Skewness	overall	0.88	0.20	0.13	1.06	N =61,823
of	between		0.17	0.23	1.00	n =6,891
Production	within		0.10	0.21	1.55	T-bar = 8.97
Product	overall	1.85	1.58	1.00	32.00	N =61,823
Range	between		1.22	1.00	24.05	n =6,891
	within		0.66	-17.20	17.92	T-bar = 8.97

Notes. This table summarizes the variation in variables used in this study. All variables are logged values. Between Std. Dev. indicates the variation of average values over years and Within-Std. Dev. indicates the variation from the overall average at a given year. There are 61,823 observations, 6,891 firms, and average of 8.97 producing years production per firm over the 1989 – 2009 periods. Revenue is deflated by GDP deflator.

TABLE II. The Number of Firms, Average Product Range, and Average Skewness of Production

Year		1989	1991	1993	1995	1997	1999	2001	2003	2005	2007	2009
1. The number of Firms												
Firms	Single	428	752	1,269	1,715	1,785	1,974	2,052	2,381	2,376	2,136	1,657
	Multi	498	703	1,036	1,236	1,276	1,401	1,370	1,531	1,520	1,419	1,152
	Total	926	1,455	2,305	2,951	3,061	3,375	3,422	3,912	3,896	3,555	2,809
2. Average Product Range with and without Single Product Firms												
With Single Product Firms		2.47	2.18	2.01	1.90	1.88	1.82	1.77	1.73	1.74	1.78	1.81
Without Single Product Firms		3.72	3.44	3.25	3.15	3.11	2.98	2.93	2.87	2.90	2.94	2.97
3. Average Skewness of Production with and without Single Product Firms												
With Single Product Firms		0.823	0.846	0.855	0.867	0.870	0.877	0.881	0.886	0.888	0.884	0.882
Without Single Product Firms		0.671	0.682	0.678	0.681	0.689	0.703	0.704	0.709	0.712	0.709	0.711

Notes. This table shows the average values of firms, product range, and skewness of production. Row 1: summaries the number of firms by year. Single indicates single-product firms and Multi indicates multi-product firms. Row 2: summaries the average number of products per firm. Row 3: shows the degree of concentration in production over products. Skewness of production ranges from 0 to 1.

TABLE III. The Share of Firms by Changes in Product Range

	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008
1. The Share of Firms by Changes in Product Range, %										
-5+	-	0.1	-	0.0	0.1	0.1	0.1	0.1	0.0	-
-4	0.2	0.1	0.0	0.0	0.1	0.1	0.2	0.1	0.1	0.0
-3	0.4	0.4	0.3	0.1	0.1	0.3	0.2	0.1	0.1	0.2
-2	0.9	0.6	0.8	0.9	0.7	0.7	0.8	0.6	0.9	0.7
-1	4.6	4.3	4.6	4.8	5.1	5.2	4.8	4.2	4.6	4.1
0	56.9	66.0	66.1	79.9	76.4	82.1	75.7	81.9	84.3	85.6
1	5.5	5.9	6.5	5.2	5.7	4.1	4.4	5.0	5.1	5.2
2	1.4	0.8	1.0	1.1	0.6	0.5	0.6	0.6	0.8	0.5
3	0.3	0.2	0.2	0.2	0.3	0.1	0.2	0.1	0.3	0.2
4	-	0.1	0.3	0.0	0.0	0.0	0.1	0.1	0.1	0.1
5+	0.1	0.2	0.1	0.0	0.1	0.0	-	0.1	0.0	0.0
2. The Share of New Born Firms, %										
New Firms	29.7	21.3	20.0	7.8	10.8	6.8	13.1	7.1	3.8	3.3
3. Total Number of Firms										
Total Firms	1,264	1,777	2,738	3,024	3,247	3,366	3,710	3,973	3,746	3,315

Notes. Row 1: summarizes the share of firms by changes in product range. The first column shows the changes in product range, and the other columns show corresponding shares of firms by %. The value -1 in the first column indicates a firm reduces a product range by -1 compared to previous year product range. Row 2: summaries the share of the newly establishing firms. The sum of Row 1 and Row 2 is 100 %. Row 3: shows the total number of firms by year.

TABLE IV. The Share of Firms by Changes in Skewness of Production

	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008
1. The Share of Firms by Skewness of Production, %										
-0.8 ~ -0.7	0.1	-	-	-	0.0	-	-	-	-	0.0
-0.7 ~ -0.6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	-	0.0
-0.6 ~ -0.5	-	0.1	0.0	0.1	0.2	0.0	0.1	0.1	0.1	0.0
-0.5 ~ -0.4	0.6	0.5	1.0	0.6	0.8	0.5	0.5	0.5	0.6	0.4
-0.4 ~ -0.3	0.6	0.6	0.8	0.6	0.7	0.6	0.7	0.7	0.5	0.5
-0.3 ~ -0.2	1.1	0.8	1.2	0.9	1.0	0.9	1.1	1.1	1.4	0.8
-0.2 ~ -0.1	1.9	3.7	2.6	2.8	2.7	2.1	2.4	2.3	2.6	2.9
-0.1 ~ 0	15.1	14.7	14.2	13.9	12.8	14.5	12.3	13.9	15.9	16.7
0 ~ 0.1	46.7	55.1	55.3	68.7	65.7	69.8	65.0	69.3	70.5	70.5
0.1 ~ 0.2	2.2	1.9	2.7	2.5	2.8	2.4	2.4	2.5	2.1	2.9
0.2 ~ 0.3	1.1	0.5	0.8	0.9	1.0	1.0	0.9	1.3	1.1	0.8
0.3 ~ 0.4	0.3	0.3	0.8	0.6	0.7	0.7	0.6	0.7	0.6	0.5
0.4 ~ 0.5	0.4	0.3	0.5	0.5	0.5	0.3	0.7	0.5	0.7	0.4
0.5 ~ 0.6	0.1	-	0.0	0.1	0.1	0.2	0.2	0.2	0.1	0.1
0.6 ~ 0.7	-	-	-	-	0.1	0.0	-	0.0	0.0	0.0
2. The Share of New Born Firms, %										
New Firms	29.7	21.3	20.0	7.8	10.8	6.8	13.1	7.1	3.8	3.3
3. Total Number of Firms										
Total Firms	1,264	1,777	2,738	3,024	3,247	3,366	3,710	3,973	3,746	3,315

Notes. Row 1: summarizes the share of firms by changes in skewness of production. The first column shows the range of changes in skewness of production, and the other columns show corresponding shares of firms by %. The range of -0.8~-0.7 in the first column indicates a firm reduces its skewness of production by the value between -0.8 and -0.7 as compared to the previous year skewness of production. Row 2: summaries share of the newly established firms. The sum of Row 1 and Row 2 is 100 %. Row 3: shows the total number of firms by year.

TABLE V. Correlation Diagnostic between Product Range and Skewness of Production

Correlation Coefficient	VIF	SQRT VIF	Tolerance	R-Squared
-0.72	2.07	1.44	0.4822	0.5178

Notes. VIF is the abbreviation for Variance Inflation Factor.

Table VI. Estimating Production Function

Coefficients on	(1) Two-Stage Procedure (Loecker's Approah)	(2) OLS w/o lagged values	(3) OLS w/ lagged values	(4) 2SLS
Capital	0.338*** (0.0048)	0.3347*** (0.0670)	0.4641*** (0.0080)	0.3386*** (0.0086)
Labor	0.2408*** (0.0037)	0.2329*** (0.0056)	0.1720*** (0.0066)	0.2363*** (0.0078)
Material	0.4505*** (0.0035)	0.4586*** (0.0046)	0.3954*** (0.0059)	0.4500*** (0.0055)
Skewness	0.0760*** (0.0280)	-0.0820 (0.0514)	0.0165 (0.0589)	-0.0671 (0.0712)
Product Range	0.2696*** (0.0033)	-0.1436 (0.2173)	-0.0502*** (0.0146)	1.8506 (4.5314)
Interaction of Skewness and Product Range	-	0.0494*** (0.0161)	0.0264 (0.0183)	0.0464** (0.0227)
Section's demand	All positive and significant	One is significant and positivie. 8 are insignificant	One is significant and positive. 8 are insignificant	9 are insignificant
Product and Time FE	Y	Y	Y	Y
No. of obs	10803	10803	10803	10803
Adjust R^2	-	0.9242	0.8861	0.9327 (Centered R^2)

Notes. This table shows the estimation results of production function. All variables are logged values by firm. The dependent variable is the deflated revenue. Column (1) is the results using De Loecker (2011)'s approach. Interaction of skewness of production and product range is not included. Column (2) is the OLS regression results without lagged variables. Column (3) is the OLS regression results with lagged variables. Labor, material, skewness of production, product range, interaction of skewness and product range are lagged due to correlation between unobserved TFP and variables for other input and intra-firm resource reallocation. Column (4) is Two Stage Least Square Estimation (2SLS) results with instrumented variables as in Column (3). All regressions do not include a constant term due to dummies for product and year. Standard Errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

Table VII. Estimating the relationship between revenue and TFP

Coefficient on	OLS	Support	
Previous TFP	0.6085*** (0.1174)	0.3783	0.8387
Constant	1.4816*** (0.0270)	1.4287	1.5344
No. of obs	10803		
Adjust R^2	0.0024		

Notes. This table examines the relationship between firms' revenue and TFP. Dependent variable is revenue which is deflated by GDP deflator. It exploits calculated TFP as a residual after generating the Cobb-Douglas production function. Previous TFP is used with the assumption that firms need some time to adjust their organization and production. All variables are logged values by firm. Standard Errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

Table VIII. Estimating the relationship between product range and TFP

Coefficient on	OLS	Support	
Previous TFP	-1.7173*** (0.1227)	-1.9579	-1.4767
Constant	1.9188*** (0.0282)	1.8636	1.9740
No. of obs	10803		
Adjust R^2	0.0178		

Notes. This table examines the relationship between firms' product range and previous TFP. It exploits calculated TFP as a residual after generating the Cobb-Douglas production function. All variables are logged values by firm. Standard Errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

Table IX. Estimating Law of Motion on TFP

Coefficient on	OLS	Support	
Previous TFP	0.8080*** (0.0058)	0.7966	0.8195
Skewness	-0.0046 (0.0061)	-0.0165	0.0074
Product Range	-0.0034*** (0.0010)	-0.0054	-0.0014
Interaction of Skewness and Product Range	0.0027 (0.0018)	-0.0007	0.0062
Constant	-0.0236*** (0.0059)	-0.0352	-0.0119
No. of obs	10803		
Adjust R^2	0.65		

Notes. This table examines the law of motion on TFP. It exploits calculated TFP as a residual after generating the Cobb-Douglas production function. All variables are logged values by firm. Standard Errors are in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.