A METHOD FOR ESTIMATING THE ELASTICITY OF SUBSTITUTION AND IMPORT SENSITIVITY BY INDUSTRY

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Abstract

We estimate the elasticity of substitution for specific manufacturing industries using a structural model of international trade in differentiated products and data on industry profit margins from the 2012 Economic Census. Then we use these elasticity estimates, along with import penetration rates in U.S. manufacturing industries, to estimate the sensitivity of domestic shipments to changes in tariffs and other import costs.

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1 Introduction

The elasticity of substitution between domestic and imported varieties of a particular good is one of the key parameters in modern trade theory. The magnitudes of these elasticities serve as important inputs in model-based analysis of trade policy. Within a Constant Elasticity of Substitution (CES) demand framework, the elasticity of substitution effectively determines the magnitudes of changes in trade patterns in response to changes in tariff rates and other trade policies.

There is a large econometric literature devoted to estimating the elasticity of substitution for different industries. Within this literature, there is considerable variation in estimates of the elasticity, reflecting differences in data sources and estimation techniques. Broadly, the current estimation approaches can be separated into those that rely on variation in import prices due to different trade costs of partners such as Hertel, Hummels, Ivanic and Keeney (2007) and Caliendo and Parro (2015); and studies that rely on the variance in the supply and demand shocks in a system of simultaneous equations that was first proposed in Feensta (1994) and later modified by Broda and Weinstein (2006) and Soderbery (2015). However,there are certain limitations when using either of these approaches to obtain elasticity estimates in policy applications. For trade cost based methods, the higher data requirements makes it more challenging to estimate the elasticities of substitution for more disaggregate industries. While the systems method does not require additional information beyond trade flows, the assumption of uncorrelated supply and demand errors in small samples can often lead to biased estimates, according to Soderbery (2015).

In this paper, we contribute to this literature with a new set of elasticity estimates that mostly corroborate, but in some cases challenge, the estimates in the literature. We develop a practical method for estimating the elasticity of substitution that relies on the structural relationship between the price-cost markup and the elasticity of substitution in industries operating under monopolistic competition. Notably, this approach is consistent with the structural model of trade in differentiated products in Krugman (1980) and the more recent literature with firm heterogeneity in Melitz (2003), Chaney (2008) and Melitz and Redding (2015). Using publicly available data from the 2012 Economic Census for manufacturing industries, we are able to compute elasticities of substitution at the level of three-digit, four-digit, and six-digit NAICS codes.

Our industry-specific elasticity estimates can be used as inputs into complex simulation models or in simpler calculations of economic effects. As an illustrative application, we combine the elasticity estimates with data on industry-level import penetration rates to calculate the changes in the domestic shipments of incumbent U.S. producers that would result from a hypothetical 10% decrease in the costs of competing imports. This import sensitivity measure can be used to quantify the impact of change in tariffs, exchange rates, or other types of foreign cost shocks. At the three-digit level, we estimate that the U.S. industries that would be most impacted by changes in the costs of imports are manufactures of leather, apparel, transportation equipment, and primary metals.

The rest of the paper is presented in five parts. Section 2 presents the theoretical framework. Section 3 describes data sources and limitations. Section 4 reports our estimates of the elasticity of substitution by industry. Section 5 applies the estimates to calculate the import sensitivity of U.S. manufacturing industries. Section 6 concludes.

2 Theoretical Framework for Estimating the Elasticity

The models of monopolistic competition and trade in differentiated products in Krugman (1980), Melitz (2003), Chaney (2008), Helpman, Melitz and Rubinstein (2008), and subsequent studies assume that consumers have constant elasticity of substitution (CES) preferences with elasticity σ.[1] In these models, there is a continuum of firms, each with monopoly power in the unique variety that it produces. The assumption of a continuum of varieties simplifies the pricing decision of the firms. Each firm takes the industry price index as given, since its own contribution to this index is infinitesimal by assumption. In this case, each firm perceives the own-price elasticity of demand for its product to be a constant that is equal to $-\sigma$.[2] Further, these models also assume that the firm faces constant marginal costs that are equals to their average variable costs.

The mark-up of each firm, m, is defined as the difference between price (p) and marginal cost (c) divided by price.

$$m = \frac{p - c}{p} \tag{1}$$

At the firm's profit-maximizing price, this mark-up is equal to the reciprocal of the absolute value of the constant own-price elasticity. The elasticity of substitution σ is simply the reciprocal of this mark-up.

$$\sigma = \frac{1}{m} = \frac{p}{p - c} \tag{2}$$

Within the modeling framework, this inverse relationship between σ and m applies to the data for each firm in the industry and also to aggregated data for the industry as a whole. This remains true even in Melitz-Chaney models where firms face heterogeneous costs within the industry and so can charge different prices.[3]

[1] The monopolistic competition framework was introduced in Dixit and Stiglitz (1977).

[2] While the Melitz-Chaney framework is commonly used in trade models with firm heterogeneity, there are trade models that can incorporate firm heterogeneity without assuming constant mark-ups. See for instance Melitz and Ottaviano (2008) and Bernard, Eaton, Jensen and Kortum (2003).

[3] Suppose there are n firms in the industry with constant but heterogeneous marginal costs c_i for $i = 1, ..., n$. Then the aggregation for the entire industry is simply given as:

$$\sum_{i=1}^{n} p_i q_i = \frac{\sigma}{\sigma - 1} \sum_{i=1}^{n} c_i q_i$$

3 Data Sources and Limitations

The source for the data that we use to calculate industry mark-ups is the 2012 Economic Census of the United States.[4] In this paper, we analyze industries at the level of three-digit, four-digit, and six-digit NAICS codes. The total value of shipments and receipts for services (TVS) is a measure of net selling values at the factory gate. Annual payroll (PAY) includes all forms of compensation for all employees. Production worker annual wages (PWW) includes all compensation for workers up through the line-supervisor who engaged in fabricating, processing, assembling, and related production activities. The total cost of materials (TCM) are the direct charges for materials consumed, including parts, fuel, power, resales, and contract work.

The source for the U.S. import and export data that we use to calculate the import sensitivity is the USITC's Trade Dataweb.[5] Annual industry imports for consumption are valued on a landed duty paid basis. Domestic exports are valued on a free along-side ship basis.

Assuming constant marginal costs, the mark-up in (2) can be expressed in terms of sales (TVS) and total variable costs (TVC):

$$m = \frac{pq\ -\ cq}{pq} = \frac{TVS - TVC}{TVS} \tag{3}$$

We calculate two alternative measures of mark-ups, based on different assumptions about whether specific cost categories are treated as fixed or variable costs. This generates a range for the estimated mark-up, and consequently for the estimates of σ. The high estimate m_1 assumes that the wage payments to production workers are the only part of the payroll that

[4] These data are available at `https://www.census.gov/data/tables/2012/econ/census/manufacturing-reports.html`.

[5] These data are available at `https://dataweb.usitc.gov/`.

is a variable cost.[6] The low estimate m_2 assumes that the entire payroll is a variable cost, so $m_2 < m_1$. The cost of materials may include some fixed costs, but we assume they are all variable costs. We assume that all other expenses of the industries are fixed costs.

$$m_1 = \frac{TVS - (PWW + TCM)}{TVS} \tag{4}$$

$$m_2 = \frac{TVS - (PAY + TCM)}{TVS} \tag{5}$$

We use m_1 and m_2 to calculate a high and low estimate of the elasticity of substitution for each industry, with $m_2 < m_1$ implying that $\sigma_1 < \sigma_2$.

$$\sigma_1 = \frac{1}{m_1} \tag{6}$$

$$\sigma_2 = \frac{1}{m_2} \tag{7}$$

One advantage of our approach to estimating the elasticity of substitution is that these simple calculations generate a full set of σ estimates for detailed manufacturing industries. A second advantage is that the data are from a reliable official census that is relatively recent and periodically updated.[7] The greatest limitation of our approach is that the calculation of marginal costs is best approximate given the data available.

[6]It assumes that wage payments to non-production workers are fixed costs.

[7]It will be easy to update the estimates with the release of 2017 Economic Census data scheduled for September 2019, or they can be updated using Annual Survey of Manufactures data for other years.

4 Estimates of the Elasticity of Substitution

Table 1 reports our high and low estimates of the elasticity of substitution for the NAICS three-digit industries. The estimates range from 1.8 to 7.0, with a median elasticity of 2.6. The highest values are for the petroleum and coal products industry, followed by the primary metals, food manufacturing, wood products, and transportation equipment industries. Sectors with the lowest values include beverage and tobacco products, nonmetallic mineral products and miscellaneous manufacturing.

It is instructive to compare the estimates in Table 1 to other estimates of sectoral elasticities found in the literature. Caliendo and Parro (2015) find a median elasticity of 3.9 for the manufacturing sectors, with elasticity estimates ranging from a low of 0.4 (other transport) to a high of 64.1 (petroleum). Hertel et al. (2007) find a higher median elasticity of 6.5 across 40 GTAP sectors, with the largest elasticity estimated for natural gas (34.4) and the lowest for other mineral products (1.8). At the aggregate level, Head and Ries (2001) estimate elasticity values between 7 and 11.4, while Romalis (2007) finds values between 4 and 13. Based on these studies, we can determine that the sectoral trade elasticities in Table 1 are concentrated within the lower end of the range of the elasticity estimates found in the literature.

Table 2 reports the median, minimum, and maximum values for both the high and low estimates of the elasticity of substitution at the following levels of aggregation: three-digit NAICS, four-digit NAICS, and six-digit NAICS industries. We see that manufacturing industries associated with dairy products and petroleum and coal products have a higher elasticity of substitution while manufacturing industries with tobacco manufacturing have the lowest elasticity of substitution. We also note that the estimates of the elasticity are similar at different levels of industry aggregation; they are not necessarily larger when the industries are further disaggregated. In contrast, Broda and Weinstein (2006) using a system method of estimation on U.S. import data find that the elasticity estimates depend on the level of aggregation so that varieties appear to be closer substitutes as product categories become more disaggregated. For instance, they find that the median elasticity is 3.1 at the ten-digit HTS level and 2.2 at the three-digit HTS level and are able to reject the hypothesis that the median at different levels of aggregation are the same.[8] However, no such systematic difference is present in the median estimates generated by Soderbery (2015) for the eight and ten digit HTS levels, finding medians of 1.86 and 1.91 respectively. Like Broda and Weinstein (2006), Soderbery (2015) also uses a system approach for their estimation, but one that is better able to account for small-sample biases and correlations between supply and demand errors. So it is not clear, based on these prior studies, if the absence of higher elasticity estimates at the more disaggregate sectors in Table 2 is in itself indicative of any broader issue for our estimation framework.

5 Import Sensitivity Calculations

The elasticity of substitution is an important input in complex industry-specific or economy-wide simulation models, but it can also be combined with import share data to generate a simple estimate of the sensitivity of U.S. manufacturing firms to changes in import costs. This relationship can be easily derived under a CES demand with constant expenditure shares at the product level along with monopolistic competition and constant marginal costs.[9]

We calculate the industry import penetration ratio S using data on the values of imports (M), exports (X), and total shipments of the domestic industry (Y) for the NAICS code corresponding to the estimate of σ.

[8] In terms of averages, the elasticity falls much more dramatically, from 12 at the ten-digit (HTS) level to 4 at the three-digit (HTS) level for the same sample period.

[9] See Ahmad (2019) for more details.

$$S = \frac{M}{Y - X + M} \tag{8}$$

Equation (9) represents a log-linear approximation of the percent change in the quantity of domestic shipments of incumbent domestic producers (Q) resulting from a hypothetical 10% decrease in the cost of all imports in the industry.

$$\%\Delta Q \ = \ (\sigma - 1) \ S \ (-10\%) \tag{9}$$

This is an estimate of the effect on each incumbent producer in a Krugman model with representative firms, or as the adjustments made along the intensive margin of trade in a Melitz-Chaney model with heterogeneous firms, as long as prices are exogenously determined by wage rates in other sectors, as in Chaney (2008).[10]

We calculate import penetration rates and import sensitivity for the NAICS three-digit and four-digit codes.[11] Table 3 reports the import penetration rates for all U.S. imports and, separately, for U.S. imports from China. Table 4 reports the sensitivity estimates for both categories of imports for the NAICS three-digit industries using σ_1, the low estimate of the elasticity of substitution.[12] In the column corresponding to an increase in the cost of all imports, the largest impacts are in the leather and allied product manufacturing and apparel industries, both over -10%. These mostly reflect the very high import penetration rates in these industries. The second highest group, with effects around -10%, are the transportation equipment and primary metals industries. These mostly reflect relatively high values of σ. The third highest group, with effects between -6 and -9%, are the electrical equipment,

[10]However, Chaney (2008) shows that aggregate trade effects do not depend on σ when firm heterogeneity in productivity is characterized with a Pareto distribution, because the negative adjustment on the intensive margin of trade with a larger value of σ is exactly offset by the positive adjustment on the extensive margin of trade.

[11]We do not calculate these measures for the six-digit codes, because it is more difficult to concord domestic production data to trade data at this level of aggregation.

[12]The full set of estimates for all of the NAICS three-digit and four-digit industries and both categories of imports are available at `https://www.usitc.gov/data/pe_modeling/index.htm`.

computer and electronic products, and textile manufacturing industries. These mostly reflect high import penetration rates. In the column corresponding to an increase in the cost of imports from China only, the largest impacts are in the leather, apparel, and textile product industries.

6 Conclusions

Our approach to estimating the elasticity of substitution for detailed manufacturing industries has practical data requirements yet it produces useful information and a starting point for further analysis. The strength of the approach is its simplicity and ability to generate estimates at the detailed industry level. However, it is important to note that this estimation approach is based on a structural relationship between elasticity of substitution and markup and so may not be appropriate for industries that deviate from monopolistic competition such as those characterized by concentrated firms or even a single large firm that has significant market power. Moreover, this approach could be improved by quantifying each industry's marginal costs with more specific cost data or by directly estimating marginal costs.

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Table 1: Estimates of the Elasticity of Substitution for Three-Digit Industries

Industry (NAICS code)	σ_1	σ_2
Food Manufacturing (311)	3.4	3.7
Beverage and Tobacco Product Manufacturing (312)	1.8	1.9
Textile Manufacturing (313)	3.1	3.6
Textile Product Manufacturing (314)	3.1	3.8
Apparel Manufacturing (315)	2.6	3.4
Leather and Allied Product Manufacturing (316)	3.1	3.9
Wood Product Manufacturing (321)	3.4	4.1
Paper Manufacturing (322)	2.6	2.8
Printing and Related Support Activities (323)	2.2	2.8
Petroleum and Coal Products Manufacturing (324)	6.7	7.0
Chemical Manufacturing (325)	2.3	2.5
Plastics and Rubber Products Manufacturing (326)	2.7	3.2
Nonmetallic Mineral Product Manufacturing (327)	2.3	2.6
Primary Metal Manufacturing (331)	3.8	4.2
Fabricated Metal Product Manufacturing (332)	2.5	3.1
Machinery Manufacturing (333)	2.6	3.1
Computer and Electronic Product Manufacturing (334)	2.0	2.7
Electrical Equipment, Appliance, and Component Manufacturing (335)	2.4	2.9
Transportation Equipment Manufacturing (336)	3.4	4.1
Furniture and Related Product Manufacturing (337)	2.4	2.9
Miscellaneous Manufacturing (339)	1.8	2.2

Table 2: Elasticity Estimates

Elasticity	Summary Statistics	NAICS3	NAICS4	NAICS6
σ_1	Median	2.6	2.5	2.5
	Range	[1.8, 6.7]	[1.3, 6.7]	[1.3, 11.6]
	High NAICS Sector	324	3241	311512
	Low NAICS Sector	312	3122	312230
	Number of Sectors	21	86	362
σ_2	Median	3.1	3.1	3.1
	Range	[1.9, 7.0]	[1.3, 7.8]	[1.3, 12.8]
	High NAICS Sector	324	3161	311512
	Low NAICS Sector	312	3122	312230
	Number of Sectors	21	86	362

Table 3: U.S. Import Penetration Rates (Percentage Points)

NAICS Three-Digit Industry	All Imports	Imports from China
Food Manufacturing (311)	7.8	0.6
Beverage and Tobacco Product Manufacturing (312)	12.4	0.0
Textile Manufacturing (313)	28.5	7.4
Textile Product Manufacturing (314)	50.9	28.1
Apparel Manufacturing (315)	91.2	36.6
Leather and Allied Product Manufacturing (316)	94.9	64.6
Wood Product Manufacturing (321)	16.2	4.2
Paper Manufacturing (322)	11.5	1.6
Printing and Related Support Activities (323)	6.8	3.2
Petroleum and Coal Products Manufacturing (324)	15.8	0.0
Chemical Manufacturing (325)	26.6	2.1
Plastics and Rubber Products Manufacturing (326)	20.7	6.9
Nonmetallic Mineral Product Manufacturing (327)	18.5	6.4
Primary Metal Manufacturing (331)	34.9	1.6
Fabricated Metal Product Manufacturing (332)	17.6	5.4
Machinery Manufacturing (333)	37.6	6.6
Computer and Electronic Product Manufacturing (334)	65.0	29.1
Electrical Equipment, Appliance, and Component Manufacturing (335)	55.7	21.6
Transportation Equipment Manufacturing (336)	36.4	1.5
Furniture and Related Product Manufacturing (337)	33.9	19.6
Miscellaneous Manufacturing (339)	50.1	18.3

Table 4: Estimates of Import Sensitivity (Percentage Points)

NAICS Three-Digit Industry	All Imports	Imports from China
Food Manufacturing (311)	-1.8	-0.1
Beverage and Tobacco Product Manufacturing (312)	-1.0	0.0
Textile Manufacturing (313)	-6.1	-1.6
Textile Product Manufacturing (314)	-10.6	-5.8
Apparel Manufacturing (315)	-14.8	-6.0
Leather and Allied Product Manufacturing (316)	-19.9	-13.5
Wood Product Manufacturing (321)	-4.0	-1.0
Paper Manufacturing (322)	-1.8	-0.2
Printing and Related Support Activities (323)	-0.8	-0.4
Petroleum and Coal Products Manufacturing (324)	-9.1	0.0
Chemical Manufacturing (325)	-3.5	-0.3
Plastics and Rubber Products Manufacturing (326)	-3.6	-1.2
Nonmetallic Mineral Product Manufacturing (327)	-2.4	-0.8
Primary Metal Manufacturing (331)	-9.9	-0.5
Fabricated Metal Product Manufacturing (332)	-2.6	-0.8
Machinery Manufacturing (333)	-5.9	-1.0
Computer and Electronic Product Manufacturing (334)	-6.2	-2.8
Electrical Equipment, Appliance, and Component Manufacturing (335)	-7.9	-3.1
Transportation Equipment Manufacturing (336)	-8.8	-0.4
Furniture and Related Product Manufacturing (337)	-4.8	-2.8
Miscellaneous Manufacturing (339)	-4.0	-1.5