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# Effects of Terms of Trade Gains and Tariff Changes on the Measurement of U.S. Productivity Growth*

Robert C. Feenstra
University of California-Davis and NBER

Marshall B. Reinsdorf
U.S. Bureau of Economic Analysis

Matthew J. Slaughter
Tuck School of Business at Dartmouth and NBER

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Abstract

Since 1995, growth in productivity in the United States has accelerated dramatically, due in large part to the information technology sector. We argue that part of the apparent speed-up in productivity growth actually represents gains in the terms of trade and tariff reductions, especially for high-tech products. Unmeasured gains in the terms of trade and declines in tariffs cause real output growth and productivity growth to be overstated. Building on the GDP function approach of Diewert and Morrison, we develop methods for measuring these effects. The growth rates of our alternative price indexes for U.S. imports are as much as 2% per year lower than the growth rate of price indexes calculated using official methods. The unmeasured terms-of-trade gains can account for close to 0.2 percentage points per year, or about 20% of the apparent increase in productivity growth for the U.S. economy. Biases in domestic price indexes, which are beyond the scope of the research in this paper, could offset some of the effects of the biases in the export and import indexes on the measurement of output and productivity growth.

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## 1. Introduction

Since 1995, growth in aggregate labor productivity in the United States appears to have accelerated markedly. The U.S. Bureau of Labor Statistics (BLS) reports that from 1973 to 1995, output per worker hour in the nonfarm business sector grew on average at just 1.40 percent per year. From 1995 through 2007 this rate accelerated to an average of 2.55 percent per year. [1] This speed-up in U.S. productivity growth would, if sustained, carry dramatic implications for the U.S. economy. At the previous generation's average annual growth rate of 1.40 percent, average U.S. living standards were taking 50 years to double. Should the more-recent average annual growth rate of 2.55 percent persist, then average U.S. living standards would take just 28 years to double – or a generation faster.

What are the explanations for this improvement in productivity growth? Among others, the declining prices of information technology (IT) products, which accelerated in the late 1990s, are often credited with key direct and indirect roles in this productivity speedup. Jorgenson (2001, p. 2) argues that: "The accelerated information technology price decline signals faster productivity growth in IT-producing industries. In fact, these industries have been the source of most of aggregate productivity growth throughout the 1990s." [2] In this paper we advance a related, but new hypothesis: that international trade, and in particular the increased globalization of the IT sector, accounts for an important part of the speed-up in productivity growth.[3]

On many measures, the global engagement of U.S. IT firms deepened after 1995—precisely

[1] These calculations are based on BLS data series #PRS85006092, as reported at www.bls.gov. Similar trends are evident in the BLS measures of multifactor productivity (MFP) for the private business sector, which we graph in Figure 1. Since 2002, however, U.S. productivity growth appears to have decelerated again.
[2] Similarly, Oliner and Sichel (2000, p. 17) state that, "In accord with the 'dual' framework described above, we have interpreted the sharp decline in semiconductor prices after 1995 as signaling a pickup in that sector's TFP growth." On the indirect role of IT in the productivity speedup, Jorgenson (2001, p. 22) finds that, "In response to these [IT] price changes, firms, households, and governments have accumulated computers, software, and communications equipment much more rapidly than other forms of capital."
[3] See also Mann (2003), who expresses a similar viewpoint.

the period of accelerated IT price declines that have been interpreted as total factor productivity (TFP). An important factor in this price decline is that IT has been the only industry to have a multilateral trade liberalization under the World Trade Organization. As we discuss in section 2, the Information Technology Agreement (ITA) was ratified in 1996 by dozens of countries accounting for nearly 95 percent of world IT trade, and the eliminated all world tariffs on hundreds of IT products in four stages from early 1997 through 2000. This timing suggests that the ITA may have played an important role in the post-1995 trends in IT prices.

To provide some suggestive evidence for this hypothesis, in Figure 1 we graph the U.S. terms of trade (the ratio of the export price index to the import price index) since 1989, together with multifactor productivity from BLS. U.S. nonfarm multifactor productivity growth rose from 0.53 percent per year during 1987-1995 to 1.41 percent per year during 1996-2006. The overall terms of trade are heavily influenced by oil imports, so to avoid that influence we use the overall export price divided by the non-petroleum import price, both from the BLS. This index of U.S. terms of trade shows a declining trend up until 1995 in Figure 1. Since 1995 – at precisely the time that productivity growth picked up – its behavior changed, with a string of solid gains in the non-petroleum terms of trade index from 1995 through 2007. The average annual gain in the BLS non-petroleum terms of trade from 1995 to 2007 is 1.0 percent, so the cumulative gain was nearly as large as the deterioration in terms of trade from the petroleum price shocks in 1973-74 and 1979-80, which totaled around 15%.

The BLS uses a Laspeyres formula to construct price indexes for imports and exports based on price quotes it collects from importing and exporting firms. We have this price data for September 1993 through December 1999, so we are able to reconstruct the Laspeyres price indexes of BLS for that time period. The ratio of our Laspeyres export price index to our

Laspeyres non-petroleum import price index is also shown in Figure 1. Our Laspeyres terms-of-trade index does not exactly match the one constructed from published BLS indexes due to missing data for some industries, but the difference is immaterial.

The finding that the U.S. terms of trade began to improve at precisely the time of the productivity speedup, as shown in Figure 1, suggests that there could be some connection between the two. Yet there are strong theoretical reasons to think that changes in the terms of trade have no effect on productivity growth. Kehoe and Ruhl (2007) have recently argued that changes in the terms of trade have no impact on productivity when tariffs are zero. When tariffs are present but small, then the impact of terms of trade shocks on productivity is correspondingly small. In section 3 we will extend the analysis of Kehoe and Ruhl (2007) from a one-sector to a multi-sector model and also consider tariff reductions. We show that tariff reductions and changes in the terms of trade have only a second-order impact on GDP and productivity.

If the terms of trade are *mismeasured*, however, the story is different. Unmeasured changes in the terms of trade have a first-order impact on reported productivity growth. In particular, if the reduction in import prices is understated, productivity growth will be correspondingly overstated. There are three reasons to expect that the U.S. terms of trade are mismeasured: (i) as already noted, the import and export prices indexes published by the BLS are Laspeyres indexes, rather than a superlative formula; (ii) in the calculation of GDP, imports exclude duties, and the BLS import indexes—which the Bureau of Economic Analysis (BEA) uses to deflate imports—also measure import prices free of tariffs; (iii) the BLS import price index does not account for increases in the variety of imports coming from new supplying countries, as analyzed by Feenstra (1994) and Broda and Weinstein (2006). In section 4 we construct price indexes that correct for these three features, and in section 5 we analyze the

impact of the ITA on the prices and variety of high-technology products. We find that high-tech products are most affected by these sources of mismeasurement.

In terms of Figure 1, our central argument is that the improvement in the terms of trade was even higher than displayed there. To preview our main results, several alternative terms-of-trade indexes based on the calculations in this paper are shown in Figure 2. We repeat the BLS and our computed Laspeyres terms of trade indexes from Figure 1, and also show: (i) an exact Törnqvist index for the terms of trade; (ii) the Törnqvist index that also incorporates tariffs into the imports prices; (ii) the Törnqvist index that incorporates tariffs and also import variety. The first two of these indexes are set equal to the Laspeyres index in September 1993, the beginning of our sample period, whereas the variety adjustment (which is annual) begins in 1990. It is noteworthy that most of the variety adjustment occurs in the period since 1995, however, just like our other adjustments. The cumulative impact of these three adjustments to the terms of trade means that the rise in the Törnqvist index, incorporating tariffs and variety, to December 1999 is nearly equal to the cumulative rise in the BLS index to December 2007 (compare Figures 1 and 2). While the BLS index rises 1.0 percent per year over 1995-2007, the Törnqvist index incorporating tariffs and import variety rises twice as fast, at 2.1 percent per year over 1995-1999. Evidently, the terms-of-trade gain for the United States since 1995 has been much higher than suggested by official price indexes.

From our aggregate terms-of-trade indexes in Figure 2, however, we cannot infer how unmeasured terms of trade gains impact reported U.S. productivity growth. The reason is that BLS's aggregate export and import indexes have no role in BEA's measures of real output growth, which drive the calculations of productivity growth. Rather, BEA constructs GDP

deflators from *detailed industry* export and import price indexes, generally the five-digit Enduse indexes produced by BLS, using a chained Fisher formula and GDP weights.

To estimate the impact of mismeasured terms of trade on reported productivity growth, we construct alternative price indexes at the 5-digit (or, if appropriate, 3-digit) Enduse level of detail. We then aggregate these detailed indexes using a chained Fisher index formula with weights that reflect their importance in GDP. The effects of the alternative detailed price indexes on the measure of productivity growth are generally the same as the ones that we calculate for real output growth.[4] The alternative detailed indexes that we consider are: Laspeyres indexes that mimic the BLS indexes; Törnqvist indexes; Törnqvist indexes including tariffs; and Törnqvist indexes including tariffs and a correction for new and disappearing varieties. These alternative 5-digit indexes are used to construct deflators for GDP and for the subset of GDP that excludes government, the gross value added of private business.[5]

By comparing productivity growth calculated from our corrected indexes with that obtained with the reconstructed BLS indexes, in section 6, we estimate the portion of reported U.S. productivity growth 1990s that was actually due to unmeasured gains in terms of trade. Our central estimates are that properly measured terms-of-trade gains can account for close to 0.2 percentage points of the post-1995 increase in productivity growth for the U.S. economy. Comparing that amount to the increase in labor or multifactor productivity, the terms of trade accounts for about 20% of the speedup in productivity growth. Section 7 concludes.

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[4] Except that, as we note below, inputs of capital services used to estimate TFP are sensitive to the price indexes for imported capital goods.

[5] In analyzing TFP for a sector, the conceptually correct measure of output is the sector's gross sales outside the sector, which equal its value added *plus* its purchases of intermediate inputs from outside the sector. The output concept for the private business sector ought therefore to equal its value added plus imported intermediate inputs, and imported intermediates ought to be included in inputs . However, including imported intermediates in inputs instead of netting them out of the output measure was found to have little effect on TFP estimates, so BLS measures the output of private business by its value added. See Gullikson and Harper (1999, p. 50 and fn 29).

## 2. Globalization of the Information Technology Industry

To gauge the role of international trade in the production of IT goods and services, a sensible starting point is to present trade flows for some specific industries. Take, for example, computers, peripherals and semiconductors (Enduse category 213) and telecommunication equipment (Enduse 214). [6] These sectors include some of the most high-profile information and communication technology (ICT) industries. Table 1 reports current-dollar trade flows in these two sectors for three years spanning most of the 1990s —1992, 1996, and 2000. The bottom of Table 1 also reports the share of economy-wide exports and imports flows accounted for by these industries. Over the 1990s exports in these sectors have been rising faster than the national total, such that their share of that total rose from 10.7 % to 15.4 %. But a more striking feature is the even higher level of imports in these sectors. Over the 1990s their national import share rose from 12 % to 16 %.

This means that these two central ICT sectors are substantial net importers whose trade imbalance widened during the decade. Within these sectors, computers and semiconductors show that smallest trade deficits, while computer accessories and telecommunication equipment have the largest deficits. By 2000 the combined trade deficit in these ICT sectors was $57 billion, or fully 17 percent of the non-oil U.S. trade deficit that year.

Table 2 offers some additional evidence on the trade intensity of IT industries, defined as trade flows as a share of output. For 1997, Table 2 shows exports, imports, and net exports, all as a share of output for two IT industries – computers and peripheral equipment, and semiconductors and electronic components. (These two IT industries differ from the Enduse classifications used in Table 1.) The key message of Table 2 is that IT industries are much more trade intensive than the overall U.S. economy. In these industries both exports and imports as a share of output range

[6] The Enduse industry classification is used by the BEA for measuring GDP, so we also use it here. Trade data for Enduse industries comes from Bureau of the Census, 1992-2000.

between 19 and 38%. These measures of trade intensity are higher than manufacturing industries in general, for which exports and imports were just 14–21% of output. Taken together, Tables 1 and 2 indicate that many of the central IT industries in the United States are more trade-intensive than is the rest of the economy, and are substantial net importers.

There are many factors that contribute to the increasing globalization of the IT industry, including the creation and spread of global production networks. But in the second-half of the 1990's, one event in the global economy was of particular importance. Under the auspices of the World Trade Organization (WTO), an Information Technology Agreement (ITA) committed signatory countries to eliminate all tariffs on a wide range of nearly 200 ICT products. These products covered both finished and intermediate goods such as computers and networking and peripheral equipment; circuit boards and other passive/active components; semiconductors and their manufacturing equipment; software products and media; and telecommunications equipment.

The original Ministerial Declaration on Trade in Information Technology Products was concluded in December 1996 at the first WTO Ministerial in Singapore. This declaration stipulated that for the ITA to take effect, signatory countries would have to collectively represent at least 90% of world trade in the covered products. The 29 original signatories accounted for only about 83% of covered trade. But by April 1997 many more countries had signed on to push the share over 90%, and the agreement entered into force in July 1997. Ultimately there were more than 50 ITA signatories that accounted for more than 95% of world trade in the covered ITA products. All ITA signatories agreed to reduce to zero their tariffs for all covered ITA products in four equal-rate reductions starting in 1997 and ending no later than the start of 2000.[7] Some developing countries were granted permission to extend rate cuts beyond 2000, but no later than 2005. Also, an ITA

[7] The four tariff cuts for the U.S. occurred in July 1997, January 1998, January 1999, and for a small number of commodities, January 2000.

Review Committee was established to monitor compliance. The overarching goal of the ITA was to eliminate world tariffs in a wide range of IT products. Thanks to the number and commitment of signatory countries, it has virtually achieved that goal.

The tariff reductions over 1997-1999 experienced by a number of U.S. ICT industries are shown in Table 3. The ITA tariff cuts are defined at the 8-digit level of the Harmonized System (HS) system, used to track import commodities. In the second column of Table 3, we indicate the percentage of import value within each industry that are covered by ITA commodities. For computers, peripherals and semiconductors, 100% of imports were included in the ITA tariff cuts. In the smaller industry of blank tapes for audio and visual use, 90% of the imports were covered by the ITA, and in the large sector of telecommunication equipment, 80% of the import value was covered by the ITA. Table 3 also includes the information for several other industries where more than 50% of import value was covered by the ITA, and industries such as industries such as business machines and equipment, and measuring, testing, and control instruments, where less than 50% of the import value was impacted by the ITA agreement.[8]

In Table 3 we show the average tariffs at the beginning of 1997, before the ITA was implemented, and at the end of 1999, when it was concluded. It is apparent that U.S. tariffs in these industries even before the ITA agreement were low: average tariffs are between one and four percent in all industries, and zero or nearly so in computer accessories and semiconductors. This means that the ITA tariff cuts for the United States were correspondingly small. But remember that the ITA was a multilateral agreement, so that tariff cuts in the U.S. could be matched by equal or larger tariff cuts abroad. For firms sourcing their IT products from overseas locations, the tariffs cuts within the ITA could therefore have a multiplied impact on lowering their import prices and costs, as we will argue in section 5.

In addition to their potential impact on prices, multilateral tariff cuts under the ITA could expand the range of supplying countries, providing differentiated varieties of IT products. Recent literature has shown how to measure the product variety of imports – or the "extensive margin" of trade (Feenstra, 1994; Hummels and Klenow, 2005; Broda and Weinstein, 2006). In the final column of Table 3 we show the growth in import varieties for each 5-digit Enduse category, reflecting the increasing number of supplying countries. The formula for import variety will be discussed in the following sections, but we note here that the increases in import variety for the ITA products was above that for all other U.S. imports, suggesting that the multilateral cuts under the ITA were effective in increasing the range of supplying countries.

**3. Measurement of Productivity Growth with International Trade**

We have seen in the previous section that tariffs on imported ICT products fell during the period covered by the ITA. In this section we describe how such declines in tariffs are incorporated into the measurement of total factor productivity (TFP) at an economy-wide level. In our exposition of the theory, we assume that productivity is measured for GDP as a whole even though, in practice, the available information only permits the private business portion of GDP to be included in the broad measure of productivity growth.

Our theoretical model extends the model of international trade and productivity of Diewert and Morrison (1986), which treats imports as intermediate inputs into the economy's GDP function. Though such a uniform treatment for all imports might appear to ignore the significant representation of finished goods in U.S. imports, Diewert and Morrison argue that imports can all be treated as intermediate inputs in the GDP function because even finished good imports generally require domestically produced distribution services to get to final consumers.

[8] Omitted from Table 3 are industries where less than 10% of imports are covered by the ITA.

Modeling all imports as intermediate inputs into the GDP function is also reasonable for our purposes, because imported finished consumer goods are treated in just the same way as imported intermediates in the import price indexes, and any bias in those indexes have the same impact on the measurement of real GDP growth.[9]

Let there be i = 1,…,M final goods, with quantities $q_i^t \geq 0$ and prices $p_i^t > 0$. In addition, there are i = 1,…,N exported outputs, with quantities $x_i^t \geq 0$ and international prices $p_{xi}^t > 0$. For simplicity, we ignore taxes or subsidies on exports. Finally, there are also i = 1,…,N imported intermediate inputs, but each of these come in j = 1,…,C varieties indexed by the country of origin. So the import quantities are $m_{ij}^t \geq 0$, with international prices $p_{mij}^t > 0$, *ad valorem* tariffs $\tau_{ij}^t$, and domestic prices $p_{mij}^t(1+\tau_{ij}^t)$.

The vector of final goods and free-trade prices is denoted by $P^t = (p^t, p_x^t, p_m^t)$, and the quantities of these goods are $y^t = (q^t, x^t, m^t) \geq 0$. Further, the import tariffs are in the vector $\tau^t$. Then the revenue function for the economy is:

$$R^t(P^t, \tau^t, v^t) \equiv \max_{y^t \geq 0} \left\{ \sum_{i=1}^{M} p_i^t q_i^t + \sum_{i=1}^{N} p_{xi}^t x_i^t - \sum_{i=1}^{N}\sum_{j=1}^{C} p_{mij}^t(1+\tau_{ij}^t)m_{ij}^t \mid y^t \in S^t(v^t) \right\} \qquad (1)$$

where $S^t(v^t)$ is a convex technology set that depends on the country's endowment of primary factors $v^t$. We assume that $S^t(v^t)$ is strictly convex, so the maximum in (1) is well-defined. The superscript t on the revenue function indicates that the technology can change over time.

[9] However investment goods that are imported directly by their final purchaser are deflated identically when they are part of imports (M in the equation GDP = C+I+G+X–M) and when they are part of investment (I), so the effects on M are canceled by the effects on I in calculations of real GDP. Therefore, including imported investment goods (such as an Airbus aircraft) as intermediate inputs in the GDP function causes a slight overstatement of the effect of mismeasured imports on estimates of real GDP. The overstatement of the effect on TFP caused by this treatment of imported investment goods is negligible, however, because over-estimation of real investment causes an over-estimation of capital services on the *input* side of the real TFP calculation.

The revenue function equals the total value added of all industries with tariffs *included* in intermediate input costs, which is the "production approach" measure of the economy's output.[10] In contrast, tariffs are *excluded* from the cost of imports in the definition of GDP because the tariff revenue remains within the importing country. Let $X^t = \sum_{i=1}^{N} p_{xi}^t x_i^t$ denote the value of exports and let $M^t = \sum_{i=1}^{N} \sum_{j=1}^{C} p_{mij}^t m_{ij}^t$ denote the value of imports at duty-free prices. Using the expenditure approach, nominal GDP is measured by:

$$GDP^t \equiv \sum_{i=1}^{M} p_i^t q_i^t + (X^t - M^t) . \tag{2}$$

Substituting for $X^t$ and $M^t$, we can re-write nominal GDP as the function:

$$G^t(P^t, \tau^t, v^t) = R^t(P^t, \tau^t, v^t) + \sum_{i=1}^{N} \sum_{j=1}^{C} p_{mij}^t \tau_{ij}^t m_{ij}^t , \tag{3}$$

where the equality is obtained using the definition of the revenue function $R^t(P^t, \tau^t, v^t)$. Equation (3) states that nominal GDP equals the aggregate output $R^t(P^t, \tau^t, v^t)$ plus tariff revenue.

The relationship between GDP and total value added is illustrated in Figure 3 for the case of an imported intermediate good, and Figure 4 for traded final goods. In Figure 3, the budget line $RP_1$ has a slope equal to the domestic (tariff-inclusive) price of the import m, with the optimal choice at point A. Total value added is $R = [f(m) - (p+\tau)m]$, labeled on the vertical axis. GDP is obtained by adding tariff revenue, $GDP = R + \tau m = [f(m) - pm]$, which is shown by the point G on the vertical axis, where the slope of the line $P_2G$ is the international price p.

In Figure 4, for an economy with a tariff on the imported good 2, profit-maximizing

[10] Assuming that tariffs are the only tax on products, $R^t(P^t+T^t, v^t)$ is the recommended measure of aggregate output and equation (3) below is the recommended "production approach" measure of GDP in the System of National Accounts or SNA (United Nations *et al.*, 1993, paragraphs 6.226-6.237.) We use the SNA definition of valued added, not the BEA one. BEA defines total gross value-added to *include* tariffs and other taxes on products.

production is at point A on $P_1R$, the budget line for domestic prices. Total value added is measured by R on the horizontal axis. Tariff revenue shifts out the budget line to $P'_1G$, and consumption is at point C. Under balanced trade, GDP equals the value of final domestic consumption (C+I+G). Measured at domestic prices and using good 1 as the numeraire, GDP is shown by point G on the horizontal axis. Hypothetically measured at international prices, GDP would equal the point G*.

To analyze the effect of tariff changes on the measure of nominal GDP, we use the GDP function in (3) to obtain the familiar optimality of free trade in a small open economy, with international prices held fixed:

**Proposition 1**

Holding fixed $P^t$ and $v^t$, the value of GDP in (3) is maximized at $\tau^t = 0$.

**Proof**: Because the derivative of the revenue function with respect to $\tau_{ij}^t$ is $-p_{mij}^t m_{ij}^t$, it follows that the first derivative of the GDP function with respect to $\tau_{ij}^t$ is zero evaluated at $\tau_{ij}^t = 0$. The second derivative is negative semi-definite because the revenue function is concave in import prices. It follows that $\tau^t = 0$ is a maximum. QED

This familiar result shows the optimality of zero tariffs in a small country, and has a very important implication for the measurement of productivity. Diewert (2006, p. 301), citing Jorgenson and Griliches (1972), observes that tariffs and similar taxes on intermediate inputs (such as excise taxes) should be included in input prices when measuring productivity change. The revenue function allows us to do this because it uses tariff-inclusive prices. We will show that even if “true” productivity change is zero, then total factor productivity as it is commonly measured will be positive when tariffs are reduced.

To show this result we begin by defining "true" productivity. A very general formulation of productivity change, due originally to Caves, Christensen and Diewert (1982) and applied to an open economy setting by Diewert and Morrison (1986), Kohli (1990, 2004, 2005, 2006) and Diewert (2008), comes from defining productivity as the shift in the economy's revenue function while holding prices and factor endowments fixed. Depending on which period's prices and endowments are chosen, productivity growth is defined as either:

$$A^{t-1} \equiv \frac{R^t(P^{t-1}, \tau^{t-1}, v^{t-1})}{R^{t-1}(P^{t-1}, \tau^{t-1}, v^{t-1})}, \text{ or } A^t \equiv \frac{R^t(P^t, \tau^t, v^t)}{R^{t-1}(P^t, \tau^t, v^t)}. \quad (4)$$

These concepts of productivity change are not measurable because both the numerator of $A^{t-1}$ and the denominator of $A^t$ are unobservable. Yet their geometric mean *can be* measured, once we assume a specific form for the revenue function. In particular, suppose that the revenue function takes a nested form. In the first stage, for imported varieties $j \in J_i \subseteq \{1,...,C\}$, we suppose that the revenue function in (1) is a CES function with elasticity $\sigma_i$,

$$\tilde{p}^t_{mi} = \left[ \sum_{j \in J_i} b_{ij} p^t_{mij} (1+\tau^t_{ij})^{-(1-\sigma_i)} \right]^{-1/(1-\sigma_i)}, \quad i=1,\ldots,N. \quad (5)$$

In the next section we will show how the import prices can be aggregated over supplying countries, obtaining $\tilde{p}^t_{mi}$, but for now suppose that these aggregate import prices are available, and denote the vector of prices by $\tilde{P}^t \equiv (p^t, p^t_x, \tilde{p}^t_m)$. Then in the second stage, across goods and factors, we suppose that the revenue function is a translog function over the prices $\tilde{P}^t$ and endowments. We further assume that the observed outputs and inputs are revenue-maximizing. Then it follows from Diewert and Morrison (1986) that:

$$\left(A^{t-1}A^t\right)^{1/2} = \left( \frac{R^t}{R^{t-1}} \right) / \left[ P_T(\tilde{P}^{t-1}, \tilde{P}^t, y^{t-1}, y^t)\, Q_T(v^{t-1}, v^t, w^{t-1}, w^t) \right], \quad (6)$$

where $P_T(\tilde{P}^{t-1}, \tilde{P}^t, y^{t-1}, y^t)$ is a Törnqvist price index over final goods, exports and imports, and $Q_T(w^{t-1}, w^t, v^{t-1}, v^t)$ is a Törnqvist quantity index over primary factors, with prices $w^{t-1}$ and $w^t$.

Equation (6) states that productivity growth can be measured by deflating the change in nominal revenue $R^t$ by its price deflator $P_T$, then comparing the estimate of real revenue growth to the growth in primary factors $Q_T$. The Törnqvist price index appearing in (6) is defined as:

$$\ln P_T(\tilde{P}^{t-1}, \tilde{P}^t, y^{t-1}, y^t)$$

$$\equiv \sum_{i=1}^{M}\left(\frac{1}{2}\right)\left(\frac{p_i^{t-1}q_i^{t-1}}{R^{t-1}} + \frac{p_i^t q_i^t}{R^t}\right)\ln\left(\frac{p_i^t}{p_i^{t-1}}\right) + \sum_{i=1}^{N}\left(\frac{1}{2}\right)\left(\frac{p_{xi}^{t-1}x_i^{t-1}}{R^{t-1}} + \frac{p_{xi}^t x_i^t}{R^t}\right)\ln\left(\frac{p_{xi}^t}{p_{xi}^{t-1}}\right)$$

$$-\sum_{i=1}^{N}\left(\frac{1}{2}\right)\left(\frac{\sum_{j=1}^{C} p_{mij}^{t-1}(1+\tau_{ij}^{t-1})m_{ij}^{t-1}}{R^{t-1}} + \frac{\sum_{j=1}^{C} p_{mij}^{t}(1+\tau_{ij}^{t})m_{ij}^{t}}{R^{t}}\right)\ln\left(\frac{\tilde{p}_{mi}^t}{\tilde{p}_{mi}^{t-1}}\right). \qquad (7)$$

Note that the weights used to sum over domestic goods, exports and imports in (7) add up to unity, and that imports receive a negative weight since they are inputs.

We can now compare "true" productivity growth in (6) to what is typically measured. The treatment of tariffs in conventional estimates of aggregate TFP differs from their treatment in (5) because nominal output is measured by $GDP^t$, not $R^t$, and because import prices are measured *without tariffs* in the index used to deflate imports. That is, conventional estimates of aggregate TFP are computed as:

$$TFP^t \equiv \left(\frac{G^t}{G^{t-1}}\right) / \left[P_E(P^{t-1}, P^t, y^{t-1}, y^t)\, Q_E(w^{t-1}, w^t, v^{t-1}, v^t)\right], \qquad (8)$$

where $G^t \equiv G^t(P^t, \tau^t, v^t)$ is nominal GDP, and $P_E(P^{t-1}, P^t, y^{t-1}, y^t)$ is an exact GDP deflator over prices of final domestic demand, exports, and duty-free imports. Notice that if the functional form for these price indexes is exact for the underlying revenue function (as is the case for the

Törnqvist index, which is exact for the translog revenue function), and if tariffs are zero, then aggregate TFP in (8) is identical to "true" productivity growth in (6). However, TFP will differ from "true" productivity when tariffs are non-zero or when the price indexes used in (8) are not exact for the underlying revenue function, as is the case for the U.S. In particular, the GDP price deflator $P_E(P^{t-1},P^t,y^{t-1},y^t)$ appearing in (8) is constructed by the BEA as a Fisher Ideal index over components of the CPI, PPI and export and import price indexes obtained from BLS. The export and import prices are Laspeyres indexes at the 5-digit Enduse level, which are duty-free.

To understand the impact of tariffs on "true" versus measured TFP, notice that "true" productivity in (6) has tariffs appearing in both the numerator (as arguments of the revenue function) and the denominator (the Törnqvist price index is tariff-inclusive). In contrast, measured TFP in (8) excludes tariffs from both the numerator (think of GDP as C+I+G+X–M, with imports measured at duty-free prices) and the denominator (since the prices in the import indexes from BLS are duty-free). So the construction of conventional TFP in (8) seems to be consistent in its treatment of tariffs. But despite this apparent consistency, the *quantities* of outputs and inputs are chosen at tariff-distorted prices in (8) and will respond to changes in tariffs. The impact of these quantity responses is shown by the following result:

**Proposition 2**

Assume that technology, prices and endowments do not change between periods, so that $S^{t-1} = S^t$, $P^{t-1} = P^t$, and $v^{t-1} = v^t$. Then reducing tariffs from $\tau^{t-1} \neq 0$ to $\tau^t = 0$ will lead to $TFP^t > 1$ in (8), even though $(A^{t-1}A^t)^{1/2} = 1$ in (6), indicating that there is no "true" productivity change.

**Proof**: The assumption that $S^{t-1} = S^t$ implies $(A^{t-1}A^t)^{1/2} = 1$ in (6). Further assuming that $P^{t-1} = P^t$ and $v^{t-1} = v^t$ means that $P_E = Q_E = 1$. From these assumptions we have $G^{t-1}(P^{t-1}, \tau^{t-1}, v^{t-1}) =$

$G^t(P^t, \tau^{t-1}, v^t)$, which is not being maximized because $\tau^{t-1} \neq 0$. From Proposition 1, reducing tariffs to zero raises GDP, so $G^t(P^t, 0, v^t) > G^t(P^t, \tau^{t-1}, v^t)$ and $TFP^t > 1$ in (8). QED

The effect of a tariff elimination on the measure of real output used to calculate TFP is illustrated in Figures 3 and Figure 4. In Figure 3, when the tariff is eliminated imports expand to m' at point B, and GDP becomes equal to total value added, as shown by the point G' = R'. Nominal value added revenue grows from R to R' on the vertical axis, reflecting the drop in tariffs, but the exact deflator for R also rises since imported inputs receive a negative weight in (7). Indeed, the growth in the deflator for R just equals the growth in R, so "true" productivity in (6) is unity. In contrast, when using (8) to measure productivity, the rise in GDP from G to G' in Figure 3 is not offset by a change in the deflator in the denominator of (8), since *duty-free* import prices are unchanged. This rise in GDP therefore shows up as productivity growth, even though the production function has not shifted.

Likewise, in Figure 4, after the tariff elimination production shifts to point B, and nominal value added falls from R to R' with the reduction in prices. Measured with prices held constant at their final values (i.e. with a Paasche quantity index), total value added rises from G* to R′, while measured with prices held constant at their original domestic values (i.e. with a Laspeyres quantity index), total value added falls from R to R*. Yet because A and B lie on the same production possibility frontier, the true difference in real output is zero. The exact quantity index therefore equals unity, implying that the "true" productivity index in (6) is unity.[11]

Real GDP, on the other hand, tracks the growth of real domestic consumption (C+I+G), with balanced trade. Tariff elimination raises real consumption because the slope of the indifference

[11] To be precise, the geometric mean of the Paasche and Laspeyres quantity indexes, which equals the Fisher Ideal index, would equal unity if the underlying technology was quadratic, since the Fisher Ideal index is exact for the quadratic technology (Diewert, 1976).

curve at point C in Figure 4 differs from the slope of the budget line based on international prices, $P_2$. The Laspeyres quantity index of GDP compares the initial GDP of G to the cost of the final bundle D at the original set of prices, so it equals G'/G> 1. The Paasche index of GDP uses the final set of prices to value both consumption bundles, so it equals R'/G* and is again greater than 1. An exact quantity index for GDP would be in between the Laspeyres and Paasche indexes, so true real GDP also rises. The rise in real GDP causes the conventional measure of productivity to rise also, as shown in equation (8). Nonetheless, the position of the PPF—which TFP is supposed to measure—is unchanged. Consequently, if import quantities respond as expected to a reduction in tariffs, TFP growth as conventionally measured will generally be positive even in the absence of any change in "true" productivity. This growth in measured TFP arises from a more efficient allocation of resources that increases the gains from trade, not an improvement in technology.

The mismeasurement in TFP due to tariff reductions is of the second-order, since the efficiency gain from eliminating tariffs is of the second-order. The following proposition shows that a similar result holds for changes in the terms of trade in the presence of tariffs:

**Proposition 3**

Assume that technology and endowments do not change between periods, so that $S^{t-1} = S^t$ and $(A^{t-1}A^t)^{1/2} = 1$ in (6). Then $TFP^t \neq 1$ in (8) due to changing prices only if $\tau^{t-1} \neq 0$ or $\tau^t \neq 0$.

The proof is immediate, since when $\tau^{t-1} = \tau^t = 0$, then measured TFP in (8) is identical to "true" productivity in (6), which is unity regardless of any change in price. Thus, a change in the terms of trade has an impact on measured TFP only if tariffs are non-zero. But if tariffs are small, then this impact is correspondingly small. This result confirms the same finding by Kim and Ruhl (2007) for a one-sector economy.

For the United States and other industrial countries, tariffs and changes in tariffs — such as occurred under the ITA — are low. Thus, we might expect that the impact of the ITA and other tariff reductions on measured TFP is small. However, an *indirect* effect of eliminating tariffs under the ITA is the entry of new countries into supplying ICT products. Provided that the new countries are supplying differentiated products, the resulting fall in the CES indexes of import prices leads to a mismeasurement of TFP that is not second-order. Furthermore, the formula bias from aggregating export and import prices with Laspeyres index formulas could also significantly distort measured TFP. As noted above, the BEA uses 5-digit Enduse export and import prices indexes that it obtains from BLS. These are Laspeyres indexes, so we denote them by $P_{xiL}^{t-1,t}$ and $P_{miL}^{t-1,t}$. The BEA uses a Fisher formula to aggregate detailed indexes from BLS to obtain the GDP deflator in (8). The difference between the Fisher and the Törnqvist formulas is negligible, so for convenience we will write the GDP deflator as the Törnqvist formula over the domestic prices and Laspeyres export and import indexes: [12]

$$\begin{aligned}
&\ln P_E(P^{t-1},P^t,y^{t-1},y^t) \\
&\equiv \sum_{i=1}^{M}\left(\frac{1}{2}\right)\left(\frac{p_i^{t-1}q_i^{t-1}}{G^{t-1}}+\frac{p_i^t q_i^t}{G^t}\right)\ln\left(\frac{p_i^t}{p_i^{t-1}}\right)+\sum_{i=1}^{N}\left(\frac{1}{2}\right)\left(\frac{p_{xi}^{t-1}x_i^{t-1}}{G^{t-1}}+\frac{p_{xi}^t x_i^t}{G^t}\right)\ln P_{xiL}^{t-1,t} \\
&-\sum_{i=1}^{N}\left(\frac{1}{2}\right)\left(\frac{\sum_{j=1}^{C} p_{mij}^{t-1}m_{ij}^{t-1}}{G^{t-1}}+\frac{\sum_{j=1}^{C} p_{mij}^{t}m_{ij}^{t}}{G^{t}}\right)\ln P_{miL}^{t-1,t}\,. \qquad (9)
\end{aligned}$$

For convenience, we also suppose that a Törnqvist formula is used for $Q_E(w^{t-1},w^t,v^{t-1},v^t)$ in (8), which is the quantity index of primary factors, just as in (6).

Comparing (6)-(7) with (8)-(9), we see that the difference between measured and "true" TFP growth is:

[12] Note that we are ignoring any issue that arise from the CPI components used in the GDP price deflator.

$$\ln TFP^t - \ln\left(A^{t-1}A^t\right)^{1/2} = \ln\left(\frac{G^t}{R^t}\right) - \ln\left(\frac{G^{t-1}}{R^{t-1}}\right)$$

$$+\sum_{i=1}^{N}\left[\left(\frac{1}{2}\right)\left(\frac{p_{xi}^{t-1}x_i^{t-1}}{R^{t-1}} + \frac{p_{xi}^t x_i^t}{R^t}\right)\ln\left(\frac{p_{xi}^t}{p_{xi}^{t-1}}\right) - \left(\frac{1}{2}\right)\left(\frac{p_{xi}^{t-1}x_i^{t-1}}{G^{t-1}} + \frac{p_{xi}^t x_i^t}{G^t}\right)\ln P_{xiL}^{t-1,t}\right]$$

$$-\sum_{i=1}^{N}\left(\frac{1}{2}\right)\left(\frac{\sum_{j=1}^{C} p_{mij}^{t-1}(1+\tau_{ij}^{t-1})m_{ij}^{t-1}}{R^{t-1}} + \frac{\sum_{j=1}^{C} p_{mij}^{t}(1+\tau_{ij}^{t})m_{ij}^{t}}{R^{t}}\right)\ln\left(\frac{\tilde{p}_{mi}^t}{\tilde{p}_{mi}^{t-1}}\right)$$

$$+\sum_{i=1}^{N}\left(\frac{1}{2}\right)\left(\frac{\sum_{j=1}^{C} p_{mij}^{t-1}m_{ij}^{t-1}}{G^{t-1}} + \frac{\sum_{j=1}^{C} p_{mij}^{t}m_{ij}^{t}}{G^{t}}\right)\ln P_{miL}^{t-1,t} \quad . \tag{10}$$

To interpret the first line of (10), notice that $G^t$ and $R^t$ differ only by tariff revenue, as in (3). For the U.S. economy as a whole, tariff revenue relative to GDP is very small, and so is the difference between $G^t$ and $R^t$, so these first terms are small. The second bracketed term depends on the difference between the "true" export prices $(p_{xi}^t / p_{xi}^{t-1})$ and Laspeyres index of export prices. If the Laspeyres index overstates the export prices, as we shall find, that tends to make measured TFP less than "true" productivity. The reverse occurs on the import side, where upward bias in the Laspeyres import prices as compared to the "true" prices $(\tilde{p}_{mi}^t / \tilde{p}_{mi}^{t-1})$ leads to an upward bias in measured TFP. We show in the following sections that the differences between the "true" prices $(\tilde{p}_{mi}^t / \tilde{p}_{mi}^{t-1})$ and the Laspeyres indexes can be substantial, especially for ICT products, while the differences on the export side is not as large; as a result, the combined effect is an upward bias in the measurement of TFP.

**4. Measurement of International Prices**

The International Price Program (IPP) of the BLS uses monthly prices for imports and exports collected from firms to construct import and export prices indexes by means of a

Laspeyres formula. We have the detailed monthly prices for September 1993 –December 1999, together with an (incomplete) set of the value weights used in the BLS indexes, as discussed in the Appendix. From these data we replicate the construction of BLS's Laspeyres indexes, and then improve on these methods by constructing Törnqvist price indexes.

Suppose that within Enduse industry i and month t, a set $J_i^t$ of price quotes is available. In the previous section we used $J_i^t$ to denote countries exporting good i to the U.S., but more generally this set denotes all available prices by country, firm, and item-level products within the industry i. The Laspeyres import price index constructed by BLS is then:

$$P_{miL}^{0,t} \equiv \sum_{j \in J_i^t} w_{mi}^0 \left( \frac{p_{mij}^t}{p_{mij}^0} \right), \tag{11}$$

where $p_{mi}^t$ is the duty-free price of import i in month t; $p_{mi}^0$ is the price of item i in a base year 0, and $w_{mi}^0$ is the annual import share is a base year 0, with $\sum_i w_{mi}^0 = 1$. Since (11) refers to the cumulative price increase from the base period 0 to month t, the month-to-month price change is obtained as the ratio of such long-term indexes:

$$P_{miL}^{t-1,t} \equiv P_{miL}^{0,t} / P_{miL}^{0,t-1}, \tag{12}$$

Analogous formulas apply on the export side.

Consider now the "true" import prices, $\tilde{p}_{mi}^t$. In the previous section we assumed that the revenue function was CES across the set of countries selling each good i. In that case, the import prices $\tilde{p}_{mi}^t$ should be obtained using an index formula that is exact for the CES function. To develop that index, suppose first that the set of countries j selling good i does not change, and denote that set by $j \in J_i$. Then the ratio of CES price aggregates can be expressed as:

$$\left(\frac{\tilde{p}^{t}_{mi}}{\tilde{p}^{t-1}_{mi}}\right) = P^{t-1,t}_{miG} \equiv \prod_{j\in J_i}\left(\frac{p^{t}_{mij}(1+\tau^{t}_{ij})}{p^{t-1}_{mij}(1+\tau^{t-1}_{ij})}\right)^{w^{t}_{mij}}, \qquad (13)$$

where $P^{t-1,t}_{miG}$ is the geometric index due to Sato (1977) and Vartia (1977), and uses the weights $w^{t}_{mij}$ which are the logarithmic mean of the import shares in periods t-1 and t, for good i and country j, constructed from the expenditure shares:

$$s^{t}_{mij} = \frac{p^{t}_{mij}(1+\tau^{t}_{ij})m^{t}_{ij}}{\sum_{i\in J_i} p^{t}_{mij}(1+\tau^{t}_{ij})m^{t}_{ij}}, \text{ with } w^{t}_{mij} \equiv \left(\frac{s^{t}_{mij}-s^{t-1}_{mij}}{\ln s^{t}_{mij}-\ln s^{t-1}_{mij}}\right)\Big/\sum_{i\in J_i}\left(\frac{s^{t}_{mij}-s^{t-1}_{mij}}{\ln s^{t}_{mij}-\ln s^{t-1}_{mij}}\right). \qquad (14)$$

That is, the Sato-Vartia index is a geometric mean over the import price ratios, computed over the countries that are supplying the import good in both periods.

As new supplying countries sell good i, we need to extend the Sato-Vartia formula to incorporate the new (and also any disappearing) countries. That formula is available from Feenstra (1994). Suppose that the set of countries supplying product i in period t, $j \in J^{t}_{i}$, has a non-empty intersection with period t-1, $J_i \equiv J^{t-1}_{i} \cap J^{t}_{i} \neq \varnothing$. Then define the terms $\lambda^{t-1}_{mi}$ and $\lambda^{t}_{mi}$ as the value of imports in periods t-1 and t from countries supplying product i in *both* these periods, relative to the total imports of product i in each period:

$$\lambda^{t}_{mi} \equiv \frac{\sum_{j\in J_i} p^{t}_{mij}m^{t}_{ij}}{\sum_{j\in J^{t}_{i}} p^{t}_{mij}m^{t}_{ij}} \leq 1. \qquad (15)$$

The terms $\lambda^{t}_{mi} \leq 1$ can be interpreted as the *period t expenditure on the goods in the set $J_i$ relative to total import expenditure on good i.* Alternatively, this can be interpreted as *one minus the share of period t expenditure on "new" selling countries (not in the set $J_i$).* When there is a greater number of new selling countries in period t, this will lower the value of $\lambda^{t}_{mi}$. Then the

ratio of CES price aggregates can be expressed as:

$$\left(\frac{\tilde{p}^{t}_{mi}}{\tilde{p}^{t-1}_{mi}}\right) = P^{t-1,t}_{miG}\left(\frac{\lambda^{t}_{mi}}{\lambda^{t-1}_{mi}}\right)^{1/(\sigma_i-1)}, \qquad (16)$$

where $P^{t-1,t}_{miG}$ is again the geometric index due to Sato (1977) and Vartia (1977). As new supplying countries sell more, then $\lambda^{t}_{mi}$ falls and so does the effective price in (16), by an amount that depends on the elasticity of substitution $\sigma_i$.

When applying equations (13) – (16) to the BLS price data, several issues arise. First, a true monthly Sato-Vartia price index $P^{t-1,t}_{miG}$ would require the use of monthly trade weights for imports. In practice the monthly trade weights are too volatile to be reliable, so we have instead used *annual* trade weights combined with *monthly* data on the import and export prices, to construct geometric indexes. The formula for the import index $P^{t-1,t}_{miG}$ is still given by (13)-(14), but now $w^{t}_{mij}$ reflects the *annual* import shares for Enduse industry i, which do not vary across months. The geometric indexes was are constructing could equally well be called Törnqvist – as we shall do – since with annual data there is no difference between the constant monthly values for $s^{t-1}_{mij} = s^{t}_{mij}$ and the weights $w^{t}_{mij}$ in (14). [13]

Second, the import values used to construct the λ-values in (15) are also annual, and are taken from Harmonized System (HS) trade data. To apply these annual HS data to equations (15) and (16), let h denote a 10-digit HS good and $J^{t}_{h}$ denote the set of countries exporting that good to the U.S. in any month within the year. Then $J_h \equiv J^{1989}_{h} \cap J^{t}_{h}$ is the intersection of that set over

[13] Normally the Törnqvist index uses the simple averages $(s^{t-1}_{mij} + s^{t}_{mij})/2$ for weights, but $s^{t-1}_{mij} = s^{t}_{mij}$ when using annual data. Then letting $s^{t-1}_{mij} \to s^{t}_{mij}$ in (16), we have $w^{t}_{mij} \to s^{t}_{mij}$, as can be shown using L'Hopitals rule.

year t and 1989, which we use as the base year. We construct the λ-ratios in two steps: (a) we use (15) to construct $(\lambda^t_{mh} / \lambda^{t-1}_{mh})$ for each HS product h, raising these to the power $1/(\sigma_h - 1)$, to reflect the elasticity of substitution between varieties coming from different countries;[14] (ii) then we take the geometric mean across products $h \in H_i$ within an Enduse industry i:

$$\Lambda^t_{mi} \equiv \prod_{h \in H_i} \left(\lambda^t_{mh} / \lambda^{t-1}_{mh}\right)^{w^t_{mhi}/(\sigma_h - 1)}. \qquad (17)$$

Note that (17) is an *inverse* measure of import variety, because having new supplying countries will lead to a lower value in (17). In Table 3 we reported the negative of the log growth rate of $\Lambda^t_{mi}$, which is the growth in import variety – adjusted by the elasticities of substitution – for each 5-digit Enduse industry. Finally, in (16) the Törnqvist index $P^{t-1,t}_{miG}$ is multiplied by $\Lambda^t_{mi}$ to obtain the price index corrected for variety.

Having obtained the import price indexes for each 5-digit Enduse industry, we do the same for exports, but in that case there is no correction for variety. We denote the Törnqvist export price indexes by $P^{t-1,t}_{xiG}$, which are used in place of $(p^t_{xi} / p^{t-1}_{xi})$ in (10). The import and export price indexes are constructed for all 5-digit Enduse industries from September 1993 – December 1999. In Figures 1 and 2 we displayed the terms of trade constructed from the Laspeyres and Törnqvist indexes for aggregate export and import price indexes. In Figure 5–12 we show the import and export indexes for the various ICT industries, normalized to 100 in September 1993 (except for the variety adjustment, which begins in 1990). Since the price indexes are very close in the early part of our sample, we start these graphs at January 1996.

In Figure 5 we show the BLS, Laspeyres and Törnqvist indexes for imports of Computers (Enduse 21300), with the adjustments for tariffs and variety. Our Laspeyres indexes differs only

[14] We use the elasticities of substitution estimated by Broda and Weinstein (2006).

slightly from the published BLS price indexes, due to missing data and concordances that are not fully accurate, but the differences seem small enough to proceed.[15] The Törnqvist index in about 10 percentage points below the Laspeyres by the end of the sample, and further adjustments for tariffs are very small. The impact of variety is to reduce the price index by a factor of 0.99 in 1996 and 0.92 in 1999, for a 7% decline in the price index between those years.[16] On the export side, in Figure 6 the BLS index, Laspeyres and Törnqvist are all very close, deviating only slightly during 1997.

In Figure 7 we show the import price indexes for Computer Accessories (Enduse 21301). In this case the Törnqvist index in about 5 percentage points below the Laspeyres by the end of the sample. While further adjustment for tariffs are very small, there is a significant impact of variety on the import price index, so that the Törnqvist index inclusive of tariffs and variety is 10 percentage points below the Laspeyres by December 1999. For exports in Figure 8, the Törnqvist index has a noticeable drop in June 1998, which much more muted in the BLS index and the Laspeyres because those indexes are using base-period weights rather and current weights, and use an arithmetic mean formula (11) rather than the geometric mean (15).

Turning to Semiconductors (Enduse 3120) in Figures 9 and 10, for imports we again see that the Törnqvist index is about 10 percentage points below the Laspeyres by the end of the period. The impact of variety is to reduce the price index by a factor of 0.97 in 1996 and 0.95 in

[15] As noted in the Appendix, two datasets were provided by BLS: September 1993 – December 1996 and January 1997 – December 1999. While our Laspeyres indexes are very close to the BLS index in the first period, we cannot duplicate BLS procedures after 1997 for several reasons. First, the prices in the second dataset had to be re-based to match the first dataset, and we could not duplicate the BLS's re-basing because the "classification group" numbers used to track commodities changed between the datasets. Second, the concordance between the "classification group" and Harmonized system (HS) numbers, used to obtain the current trade weights for the Törnqvist indexes, were incomplete due to changes in HS numbers after 1997. This led to some omitted commodities in the Törnqvist indexes. Third, in a few instances we did not have the Laspeyres weights used by the BLS after 1997. To mitigate these problems, we construct the Laspeyres and Törnqvist indexes over exactly the same set of commodities in each industry (which might differ slightly from the set used by BLS), so that differences between the Laspeyres and Törnqvist indexes are due solely to their weights and formulas, not the commodities used.

1999, so there is only slight growth in variety.[17] For exports, we see that the Törnqvist index lies substantially the Laspeyres index. This ranking of export price indexes was also found in Alterman, Diewert and Feenstra (1999). As they explain, it can be understood as resulting from technological improvement in the supply of exports, leading to higher quantities and falling prices along the foreign demand curve. So the export price index reflects substitution along foreign demand curves, and therefore the Laspeyres index overstates the increase in prices, just as the import price index reflects substitution along U.S. demand curves.

Finally, in Figures 11 and 12 we show the indexes for Telecommunications (Enduse 21400). In this case there was a significant fall in tariffs over 1996-1999. The variety adjustment is substantial, leading to a reduction in the Törnqvist index by a factor of 0.93 in both 1996 and 1999. So variety grew from its comparison year of 1989, but did not change over these three years. On the export side we see that the Törnqvist index is below the Laspeyres, which is the same pattern that occurred by Semiconductors.

To summarize the results from these four ICT industries, in every case the Törnqvist index for imports is considerably below the Laspeyres by the end of the sample period, whereas for exports the indexes differed significantly in only two cases. That means the impact of the mismeasurement of import prices will have a greater impact on TFP – leading to an upward bias – than the mismeasurement of export prices. In addition, there is a further impact of falling tariffs and rising variety on reducing the import price index. These additional impacts appear to be small in the Figures, but as we show in the next section, even small reductions in tariffs under the ITA have considerable impact on prices. In addition, variety continues to fall beyond 1999 which

[16] In Table 3 we report a 9% rise in import variety for Computers from 1996 to 2001. Therefore, an additional 2% growth in variety occurs in 2000 and 2001.

[17] In Table 3 we report a 9% rise in import variety for Semiconductors from 1996 to 2001. Since only 2% of that occurs between 1996 and 1999, the remaining 7% occurs in 2000 and 2001.

was our sample period for prices, so when investigating import variety we extend the sample to 2001 (as was used in the earlier summary in Table 3).

## 5. Impact of the ITA on Import Prices and Variety

To determine how the tariffs cuts under the ITA affected import prices, we construct a tariff index for industry i, denoted by $\text{Tar}_i^{t-1,t}$, as:

$$\text{Tar}_i^{t-1,t} = \prod_{j \in J_i} \left( \frac{1+\tau_{ij}^t}{1+\tau_{ij}^{t-1}} \right)^{w_{mij}^t} . \qquad (18)$$

In addition, we also construct a geometric index of exchange rates in Enduse industry i, $\text{Exch}_i^{t-1,t}$, which is a weighted average of the exchange rate times the producer price indexes (PPI) for U.S. trading partners. In this index we start with nominal exchange rates times the PPI for each country, average these across source countries for U.S. imports (using import country weights), and then aggregate these across commodities again using the geometric formula (with import commodity weights).

The various cumulated indexes are denoted by $P_{miG}^{0,t}$, $P_{xiG}^{0,t}$, $\text{Tar}_i^{0,t}$ and $\text{Exch}_i^{0,t}$. Using these indexes, we run the following price regression:

$$\ln P_{miG}^{0,t} = \alpha_{j0} + \sum_{k=1}^{3} \alpha_k \delta_k^t + \beta \ln \text{Tar}_i^{0,t} + \sum_{\ell=0}^{9} \beta_\ell \ln P_{miG}^{0,t-\ell} + \gamma \ln P_{iD}^{0,t} + \varepsilon_{it} , \qquad (19)$$

where: $\alpha_{i0}$ is a fixed-effect for each industry, and $\delta_k^t$ are three indicator variables for the stages of the ITA (i.e. July 1997, January 1998 and January 1999). The prices of competing products also belong in regressions of this type, and we include the domestic U.S. price $P_{iD}^{0,t}$ in industry i, as measured by the producer price index.[18]

[18] Because the producer prices indexes (PPI) are available on 4-digit standard industrial classification (SIC), we aggregate these using trade weights to obtain a PPI on the Enduse classification.

The results from this price regression are shown in Table 4. The first regressions are run over those industries where 100% of the import commodities are covered by the ITA (denoted by ITA = 1); from Table 3, these industries are computers, peripherals and semiconductors. The second regressions run over those industries where 50 – 99% of the import value covered by the ITA ($0.5 \leq ITA < 1$), and the third regressions are run over those industries where 1 – 49% of the import value is covered by the ITA ($0 < ITA < 0.5$). The final regressions are run over a control group of industries that include no ITA commodities.[19]

Looking first at the regressions for ITA = 1, which includes computers, peripherals and semiconductors, the indicator variables for the ITA tariff cuts (July 1997, January 1998 and January 1999) are all negative, indicating a drop in prices that is not accounted for by the tariff variable. The cumulative drop due to the indicator variables is 24%. The tariff variable itself has a "pass-through" coefficient of 17.2, which is much larger than normally found and indicates that the tariff declines have a *highly magnified* effect on lowering the import prices. Admittedly, the tariffs themselves are very low in these industries (see Table 3), so even with the very large pass-though coefficient, the impact of the tariff cuts on import prices is still modest. Furthermore, the pass-through estimate is sensitive to the estimation method. In addition to OLS, all regressions are estimates with "pooled mean group" (PMG), which accounts for unit-roots in the time series and is maximum likelihood for cointegrated panels.[20] The PMG estimate of the tariff coefficient falls to 4.4, which is still significantly greater than unity

Turning to the next regressions (2) and (3), these are run over industries with 50 – 99% of the import value covered by ITA products, or 1 – 49% so covered, respectively. Both product

[19] The control group of industries used in the final regressions include capital goods (Enduse 2), automobiles and parts (Enduse 3), and consumer goods (Enduse 4).

[20] The PMG estimator, coded by Blackburne and Frank (2007), is available in STATA as the `xtpmg` command. The time-series properties of the data is investigated in Bergin and Feenstra (2007).

groups indicate a tariff pass-through coefficient greater than 2 with OLS, though the PMG estimates are not significantly greater than unity. So again, there is a *magnified* impact of the ITA tariff cuts on the import prices in the point estimates. Our explanation for these results is that the ITA was a multilateral tariff reduction, with U.S. tariff reductions matched by those abroad, so with import processed in multiple countries their prices can easily fall more than the drop in U.S. tariffs. In these regressions, the ITA indicator variables are much smaller than found with ITA = 1, so that most of the impact of the ITA is through the tariff variables. The exchange rate coefficients reported are the sum of coefficients on the current and six lagged values. These estimates show that a 10% permanent depreciation of foreign currencies results in a 2.5 – 5% lowering of U.S. import prices.

The final regressions in Table 4 are for a control group of capital and consumer goods industries that do not include any commodities affected by the ITA tariff cuts. For these industries, we find a tariff coefficient between 0.5 and 1, depending on the estimation method used.[21] The fact that this control group provide the expected results for tariff pass-through gives us confidence that the magnified tariff coefficients found for industries with ITA tariff cuts really do reflect the multilateral nature of the ITA.

We have also investigated the impact of the ITA on import variety, using data from 1989 to 2001 on all 5-digit Enduse industries. Rather than attempt to structurally model the growth in import variety, we perform a simple difference-in-difference test to evaluate the impact of the ITA. We use the inverse of (17) to measure import variety on an annual basis, and specify the difference-in-difference test as:

[21] We have also estimated the price regression for subsets of the control group, which include capital goods (Enduse 2), automobiles and parts (Enduse 3), and consumer goods (Enduse 4). In each of these three categories, the tariff coefficient is insignificantly different from unity. The only Enduse category besides the ITA industries that consistently show a tariff coefficient greater than unity is Enduse 12500, which is chemicals.

$$-\ln \Lambda_{mi}^{t} = 1(\text{ITA} = 1)\cdot 1(\text{Year} \geq 1997) + 1(0.5 \leq \text{ITA} < 1)\cdot 1(\text{Year} \geq 1997) \qquad (20)$$
$$+1(0 < \text{ITA} < 0.5)\cdot 1(\text{Year} \geq 1997) + \text{Industry and year fixed effects},$$

where $1(\cdot)$ are indicator variables returning a value of unity when the statement $(\cdot)$ is true, and zero otherwise. In addition to the specification (20), we also experiment with a single indicator variable for industries with any percentage of commodities impacted by the ITA (i.e. ITA > 0), which is still interacted with the dates after the ITA was in effect (i.e. Year $\geq$ 1997). In the first panel of Table 5, we use all Enduse industries, including agriculture, raw materials, capital goods, autos, and consumer goods. In the second panel we drop agriculture and raw materials, focusing on Enduse 2 – 4 (capital, autos and consumer goods).

The first regression reported in Table 5 uses OLS, along with all Enduse industries. The interaction terms in (20) between the ITA industries and the time of the ITA agreements are insignificant in that case. In the second regression we weight the regressions by the value of imports, and in that case obtain a significant increase in import variety of 2.5% for the industries covered entirely by the agreement, i.e. computers, peripherals and semiconductors. If we omit agricultural goods and raw materials, then in the OLS regression the ITA leads to a 2.5% increase in variety for those ITA industries only partially covered by the agreements. In the weighted regression, however, we find a higher 3.7% increase in variety for the ITA industries fully covered by the agreement, and an average 2.4% increase in variety over all industries impacted by the ITA (in the final regression).[22] We turn now to the question of how the drop in prices and increase in import variety due to the ITA has influenced the measurement of productivity growth in the United States.

[22] It is worth emphasizing that because we are incorporating the elasticity of substitution $1/(\sigma_h - 1)$ into the definition of variety in (17), the *actual* increase in variety is larger than indicated by these regression coefficients, e.g. twice as high for $\sigma_h = 3$, or three times as high for $\sigma_h = 4$.

## 6. Terms of Trade and Productivity Growth for the United States

To investigate the sensitivity of estimates of productivity growth to unmeasured gains in terms of trade, we calculate alternative versions of the deflators of exports and imports on which the estimates of productivity depend. The Major Sector Productivity and Costs Program in BLS's Office of Productivity and Technology uses measures of the output of private business and nonfarm private business from BEA.[23] Therefore the relevant deflators are the ones calculated by BEA using weights from the National Income and Product Accounts (NIPAs) and price indexes for detailed items from BLS. In the case of exports and imports, the detailed price indexes are generally the 5-digit Enduse level indexes from the International Price Program.

We first replicate BLS's Laspeyres price indexes for 5-digit Enduse exports and imports to obtain a baseline for our comparisons. To obtain the building blocks for our corrected deflators, we construct parallel export and import price indexes using a Törnqvist index formula, and for imports we calculate additional sets of Törnqvist indexes that include tariffs and variety effects, as described in section 4. We then aggregate the various versions of the 5-digit Enduse indexes using the Fisher index formula price with weights from the NIPAs to obtain deflators for merchandise exports and for non-petroleum merchandise imports.

Table 6 reports the results for our Törnqvist export price indexes and the three kinds of import price indexes: the Törnqvist, the tariff-inclusive Törnqvist, and the tariff-inclusive Törnqvist adjusted for variety effects. Unsurprisingly, replacing the Laspeyres index with the Törnqvist index has a smaller effect when a Fisher index is used for higher-level aggregation than it did when a Laspeyres index was used at all stages of aggregation (as shown in Figure 1). Using the Törnqvist formula to calculate the detailed indexes reduces the growth rate of our

[23] BLS previously made a minor adjustment to BEA's output measure (Fraumeni *et al.*, p. 379), but this is no longer necessary.

aggregate Fisher export index by 0.16 to 0.66% per year, with a substantial portion of this effect coming from ICT goods. The Törnqvist formula also reduces the growth rate of the aggregate import price index by 0.35 to 0.72% per year. From 1996 to 1999, the effect on the growth rate of the terms of trade index averages about 0.2% per year. Including tariffs in the price indexes and item weights for imports raises the average effect on the terms of trade to 0.3% per year.

After also adjusting the import indexes for changes in variety we find that their growth rate is 1.1 to 1.8% per year below the growth rate of the baseline Laspeyres index in 1996-1999. The average effect in those years is about 1.5% per year, with almost 0.6 percentage points of this growth rate effect coming from ICT goods. This supports the hypothesis that entry of lower priced varieties from new sources of supply caused a substantial drop in import prices that was missed by the standard methods used to construct official indexes. The combined effect of the three index corrections on the growth rate of the terms of trade averages 1.1 percent per year in 1996-1999 (though it is virtually zero in 1995). ICT goods contribute 0.3 percentage points to this 1.1 percent per year average, or about one-quarter of the total.

Unmeasured gains of 1.1 percent per year in the Fisher terms of trade index are large enough to affect measures of aggregate output significantly starting in 1996. To investigate effects on measures of aggregate output, we use our Laspeyres export and import indexes to calculate baseline price indexes for GDP, for total value added (i.e. the revenue function), and for the value added of private business. We then compared the price indexes for these three aggregates to ones calculated using the Törnqvist export index and the tariff-inclusive Törnqvist import index adjusted for variety effects. The price indexes for value added includes tariffs in the weight for imports, as is logical when tariffs are included in the prices and weights used to calculate the import price index, like in equation (7).

We calculated the indexes for all three aggregate output concepts using both a Törnqvist formula and a Fisher formula to aggregate domestic final consumption, goods exports, services exports, non-petroleum goods imports, services imports and petroleum imports. As expected, the Törnqvist and Fisher results were identical for practical purposes.

In 1996-1999, the effect of our corrected export and import indexes on the growth rate of the price index for GDP ranged from 0.10 to 0.13 percent per year (see Table 7, section I). The effect on the Fisher price index for total value added (for which no official index exists) is 0.12 to 0.15 percent per year during that period (Table 7, section II). That is, this deflator for total value added grows by 0.12 to 0.15 percent more per year that the deflator based on the official import and export prices indexes: the slower growth of our Törnqvist import indexes, adjusted for tariffs and variety effects, leads to more rapid growth of the deflator for value-added, and therefore a slower real growth of value added. That slower growth of value added translates into slower productivity growth of the same magnitude, i.e. 0.12 to 0.15 percent slower per year. Taking into account the difference between the growth of nominal GDP and value added, which depends on the change in total tariff revenue and appears as the first two terms on the right of equation (10), has only minimal impact (as shown by the last line in section II).

If we ignore the government sector and focus on private business, then the effect on the price index for gross value added of private business ranges from 0.15 to 0.19 percent per year, with an average of 0.17 percent per year, in 1996-1999 (Table 7, section III). Again, the slower growth of our Törnqvist import indexes, adjusted for tariffs and variety effects, leads to more rapid growth of the deflator for private business value added, and therefore a slower real growth of value added. The further adjustment for changes in total tariff revenue has only minimal impact (as shown by the last line in section III). The official price index for the output of private

business in 1999 is 106.5, compared with our corrected index of 107.3, with all of the 0.8 percentage point gap coming from the four years of 1996 to 1999. Unmeasured gains in terms of trade therefore can account for about 0.2 percent per year to the official measure of productivity growth starting in 1996.

To gauge the importance of this terms-of-trade mismeasurement, recall that reported growth in U.S. nonfarm labor productivity has accelerated from 1.40 percent during 1973-1995 to 2.55 percent during 1996-2007—i.e., by about 1.15 percent per year. Our results suggest that about 17% of this reported economy-wide acceleration in labor productivity should properly be accounted for by terms-of-trade improvements. Furthermore, current BLS statistics report that U.S. nonfarm TFP growth accelerated from 0.53% per year over 1987-1995 to 1.41% per year over 1996-2006. Our results suggest that about 23% of this reported economy-wide acceleration in TFP should properly by accounted for by terms-of-trade improvements. The U.S. economy in the past decade clearly did enjoy faster productivity growth. But the magnitude of this acceleration has been overstated, with a sizable share of the gains actually being accounted for by the benefits of international trade.

Two caveats concerning the results in Table 7 is worth mentioning. First, we have included imported finished investment goods in our corrected import price indexes even though their deflators have no effect on the measurement of real GDP. These goods are deflated by import price indexes in calculating the investment component of GDP, so the effects of any bias in their price indexes cancel out when the imports and investment components of GDP are combined. Nevertheless, these price indexes *do* affect the measurement of TFP because estimates of capital services inputs are based on accumulated real net investment. Thus, for purposes of estimating effects on productivity measurement, we are correct to include imported investment

goods in our analysis.[24] In any event, these goods account for only a small fraction (probably well under a tenth) of the total effect on measured real GDP growth in 1996-1999.

Second, we simulated the BLS indexes for semiconductors in all years in Tables 6 and 7, but until 1997 BEA used the hedonic indexes of Grimm (1998) rather than indexes from BLS for semiconductors. (Even though the hedonic indexes fell faster than the matched model indexes of BLS, the change to the BLS indexes had little effect on estimates of real GDP because US trade in semiconductors was approximately balanced in the late 1990s, and the Grimm indexes and BLS indexes both tended to imply similar small gains in terms of trade for this item.) Excluding semiconductors from our analysis before 1998 would have reduced the estimates of the overall gains in terms of trade in the next to last row of Table 6 by 0.1 percentage points in 1996 and 1997. In the other years, the contribution of semiconductors alone to our overall estimate of unmeasured gains in terms of trade is very small.

**7. Conclusions**

Although the roles of import and export price indexes in productivity measurement might seem inconspicuous, for many reasons they can be very important. Unmeasured gains in the terms of trade cause real output growth and productivity growth to be overstated, and declines in tariffs can also be expected to raise productivity. Building on the GDP function approach of Diewert and Morrison, in this paper we have developed methods for measuring these effects. We have then applied this framework to the case of the U.S. productivity acceleration. Since 1995, growth in U.S. productivity has accelerated dramatically, due in large part to the information technology sector.

[24] The way capital services inputs are calculated slightly attenuates the effect on estimated TFP compared with the effect that would occur if the deflators for imported investment goods affected the output side of the calculation.

We have demonstrated that part of the apparent speed-up in productivity growth was actually gains in the terms of trade and tariff reductions, especially for IT products. In particular, we analyzed three important reasons to expect mismeasurement in the U.S. terms of trade: (i) the import and export prices indexes published by the BLS are Laspeyres indexes, rather than a superlative formula; (ii) in the calculation of GDP, imports exclude duties, and the BLS import indexes—which the Bureau of Economic Analysis (BEA) uses to deflate imports—also measure import prices free of tariffs; and (iii) the BLS import price index does not account for increases in the variety of imports coming from new supplying countries. The growth rates of our alternative price indexes for U.S. imports are as much as 2% per year lower than growth rate of the index calculated using official methods. Because non-petroleum imports amount to around 10% of GDP during our period of study of the late 1990s, this terms-of-trade gain can account for close to 0.2 percentage points per year, or about 20 percent of the apparent increase in productivity growth for the U.S. economy.

## Appendix: International Price Data

To calculate all the price indexes, we use two datasets provided by the International Price Program (IPP) program. The first dataset spans September 1993 to December 1996 and was used extensively in Alterman, Diewert and Feenstra (1999). That dataset contains long-term price relatives (that is, $p_i^t / p_i^0$) at the "classification group" level, which is similar to the 10-digit Harmonized System (HS) level. The classification groups have been carefully concorded to the HS system, so that the base-period weights (for 1990) used by the IPP program can be replaced by current annual import and export expenditures in order to calculate the Törnqvist indexes. That is, current annual weights are used in the Törnqvist index when aggregating from the classification group level to the Enduse industries.

A second dataset spans January 1997 to December 1999. The classification groups used in that dataset differ somewhat from those used in the earlier period, so we have developed an (incomplete) concordance between them. The price data available for this latter period are actually more detailed than the classification group level, and go down to the "item" level at which individual companies provide price quotes. So for this latter period, we first need to aggregate from the item level to the classification group level, and then aggregate from the classification groups to the Enduse industries. The lower-level aggregation (from the item level to the classification group) can be done using the base-period (1995) weights and the Laspeyres formula, which follows the BLS procedure. Alternatively, the lower-level aggregation can be done using the base-period weights and a geometric formula. After constructing geometric indexes at the lower-level, we proceed by applying the Törnqvist index to aggregate the indexes for the classification groups to the Enduse industries.

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## Table 1: International Trade in ICT Industries ($million)

| Industry | | 1992 | 1996 | 2000 |
|---|---|---|---|---|
| Computers (Enduse 21300) | Exports | 8,277 | 10,422 | 10,263 |
| | Imports | 5,042 | 6,927 | 14,284 |
| | Trade Balance | 3,235 | 3,495 | -4,022 |
| Computer accessories (Enduse 21301) | Exports | 16,730 | 27,550 | 34,686 |
| | Imports | 26,659 | 54,590 | 75,514 |
| | Trade Balance | -9,929 | -27,040 | -40,828 |
| Semiconductors (Enduse 21320) | Exports | 11,527 | 24,135 | 45,118 |
| | Imports | 15,477 | 36,713 | 48,341 |
| | Trade Balance | -3,950 | -12,579 | -3,223 |
| Telecommunications Equipment (Enduse 214) | Exports | 10,520 | 19,137 | 28,987 |
| | Imports | 10,773 | 14,505 | 38,203 |
| | Trade Balance | -253 | 4,633 | -9,216 |
| Total (Enduse 213+214) | Exports | 47,054 | 81,244 | 119,054 |
| | Imports | 57,952 | 112,735 | 176,343 |
| | Trade Balance | -10,898 | -31,491 | -57,289 |
| Share in Overall Trade (percent) | Exports | 10.7 | 13.3 | 15.4 |
| | Imports | 12.0 | 15.4 | 16.0 |
| | Trade Balance | 24.1 | 26.6 | 17.2 |

*Notes*: Trade exports and imports are in millions of current dollars, and trade balance equals exports minus imports.
*Source*: Trade data for Enduse industries comes from Bureau of the Census, 1992-2000. The export, import and trade balance shares are computed by dividing trade in Enduse 213+214 by total U.S. exports, non-petroleum imports, and the non-petroleum trade deficit, from *Economic Report of the President*, 2004, Table B-104.

## Table 2: Trade Intensity of IT Commodities in the 1997 Benchmark I-O Tables (percent)

| **Commodity** | **% of Commodity Output Exported** | **% of Commodity Output Imported** | **Trade Balance** |
|---|---|---|---|
| Computer & peripheral equipment | 19.2 | 37.8 | –18.7 |
| Semiconductors & Electronic components | 36.1 | 36.6 | –0.5 |
| Manufacturing Products | 13.8 | 20.5 | –6.7 |

*Source*: Calculated from the "Use of Commodities" tables in the U.S. BEA's Input-Output Accounts.

## Table 3: Features of ITA Industries

| Industry | % Imports covered by ITA | 1997 Tariff (percent) | 1999 Tariff (percent) | Variety Growth 1996-01 (percent) |
|---|---|---|---|---|
| Computers (Enduse 21300) | 100 | 1.4 | 0.3 | 9.0 |
| Computer accessories (21301) | 100 | 0.3 | 0.0 | 3.5 |
| Semiconductors (21320) | 100 | 0.0 | 0.0 | 9.2 |
| ***Average variety growth (ITA=1)*** | | | | ***7.2*** |
| Blank tapes (16110) | 91 | 1.5 | 0.0 | 0.4 |
| Telecomm equipment (21400) | 79 | 2.6 | 0.9 | 2.5 |
| Lab Instruments (21600) | 64 | 3.7 | 2.5 | 5.2 |
| Records, tapes & disks (41220) | 63 | 1.0 | 0.3 | -0.7 |
| Electrical apparatus (20005) | 54 | 2.3 | 1.5 | 3.6 |
| ***Ave. variety growth (0.5≤ITA<1)*** | | | | ***2.3*** |
| Business machines (21500) | 39 | 2.0 | 0.9 | 13.6 |
| Generators & access (20000) | 38 | 1.6 | 1.5 | 1.1 |
| Measuring, testing, control instruments (21160) | 30 | 1.8 | 1.0 | -0.3 |
| Marine engines and parts (22220)[a] | 29 | 1.6 | 0.3 | 19.7 |
| Photo, service industry (21190) | 22 | 2.1 | 1.5 | 4.9 |
| Materials handling equip (21170) | 21 | 0.4 | 0.1 | 2.8 |
| Industrial supplies, other (16120) | 20 | 2.1 | 1.7 | 2.3 |
| Industrial machines, other (21180) | 16 | 2.2 | 1.7 | 2.8 |
| ***Average variety growth (0<ITA<0.5)*** | | | | ***6.6*** |
| ***Average variety growth (ITA=0)*** | | | | ***3.8*** |

*Notes:*

a. Within marine engines and parts (22220), the product receiving ITA tariff cuts was radar equipment. Omitted from this table are industries where less than 10% of imports are covered by the ITA

## Table 4: Pass-through Regressions, Dependent Variable – Import Price

| By portion of product covered by ITA accord: | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ITA=1 | | 0.5 ≤ ITA <1 | | 0< ITA < 0.5 | | ITA=0 | |
| | OLS | PMG | OLS | PMG | OLS | PMG | OLS | PMG |
| **July 1997** | -0.10** | -0.07* | -0.01 | 0.06* | -0.02** | 0.01 | 0.003 | 0.01* |
| | (0.03) | (0.03) | (0.01) | (0.02) | (0.004) | (0.01) | (0.003) | (0.004) |
| **January 1998** | -0.07* | -0.02 | -0.005 | 0.02 | -0.001 | -0.003 | -0.002 | 0.01** |
| | (0.03) | (0.04) | (0.01) | (0.02) | (0.004) | (0.005) | (0.003) | (0.004) |
| **January 1999** | -0.07** | -0.03 | -0.02* | -0.06** | -0.02** | -0.01** | -0.01** | 0.005 |
| | (0.02) | (0.03) | (0.01) | (0.02) | (0.004) | (0.004) | (0.002) | (0.003) |
| **Tariff** | 17.2** | 4.40** | 2.18** | 2.36* | 3.13** | 1.21** | 0.53** | 1.00** |
| | (2.11) | (1.56) | (0.44) | (1.01) | (0.25) | (0.44) | (0.11) | (0.16) |
| **Exchange rate (6 lags)** | -0.08 | 0.29* | 0.22** | 0.30** | 0.28** | 0.55** | 0.28** | 0.47** |
| | (0.15) | (0.16) | (0.07) | (0.12) | (0.03) | (0.03) | (0.02) | (0.03) |
| **U.S. Price** | 0.89** | 0.83** | 0.48** | 0.25 | 0.99** | 0.31** | 0.25** | -0.02 |
| | (0.06) | (0.06) | (0.13) | (0.24) | (0.04) | (0.07) | (0.03) | (0.03) |
| **Observations** | 228 | 219 | 304 | 288 | 1,064 | 966 | 2,618 | 2,376 |
| **$R^2$** | 0.96 | | 0.77 | | 0.84 | | 0.79 | |

**Notes:** * significant at 5%, ** significant at 1%; Standard errors are in parentheses.

Regressions are run over 5-digit Enduse industries, with monthly data from September 1993 – December 1999. Regressions with ITA=1 are run over those industries where 100% of the imports are covered by the ITA; regressions with 0.5 ≤ ITA <1 are run over those industries where 50 – 99% of the import value covered by the ITA; and regressions with 0< ITA < 0.5 are run over those industries where 1 – 49% of the import value is covered by the ITA. The final regressions with ITA=0 are run over a control group of industries (Enduse 2,3,4) that do not include any ITA commodities as imports. All regressions are estimated with OLS (including fixed effects for 5-digit Enduse industries) and PMG (pooled mean group), which corrects for unit-roots in the time series. The OLS regressions include 6 lags of the exchange rates, whereas the PMG routine chooses its own lag length for the exchange rate and other dependent variables.

## Table 5: Difference-in-Difference Test, Dependent Variable – Import Variety

| Enduse categories included in analysis: | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **All Enduse industries** (agriculture, raw materials capital, autos, and consumer goods) | | | | **Enduse 2-4** (capital, autos, consumer goods) | | | |
| | OLS | WLS | OLS | WLS | OLS | WLS | OLS | WLS |
| **(ITA=1)·(Year≥1997)** | 0.017 | 0.025** | | | 0.031 | 0.037** | | |
| | (0.023) | (0.009) | | | (0.020) | (0.01) | | |
| **(0.5≤ITA<1)·(Year≥1997)** | -0.028 | -0.004 | | | -0.013 | 0.010 | | |
| | (0.018) | (0.01) | | | (0.017) | (0.014) | | |
| **(0<ITA<0.5)·(Year≥1997)** | 0.010 | 0.003 | | | 0.025** | 0.016 | | |
| | (0.011) | (0.009) | | | (0.010) | (0.010) | | |
| **(ITA >0)·(Year≥1997)** | | | 0.002 | 0.010* | | | 0.019** | 0.024** |
| | | | (0.009) | (0.006) | | | (0.009) | (0.007) |
| **Observations** | 1,837 | 1,837 | 1,837 | 1,837 | 962 | 962 | 962 | 962 |
| **$R^2$** | 0.37 | 0.56 | 0.36 | 0.56 | 0.29 | 0.49 | 0.29 | 0.49 |

**Notes:** * significant at 10%, ** significant at 5%; Standard errors are in parentheses.

Regressions are run over 5-digit Enduse industries, with annual data from 1989 – 2001. All regressions are estimated with OLS and WLS (using the customs value of imports as weights), and include fixed effects for 5-digit Enduse industries and for years. The first set of regressions include all 5-digit Enduse industries, and the second set include only the Enduse industries beginning with 2, 3, or 4.

## Table 6: Effect of Lower-level Index Formula on Aggregate Fisher Price Indexes for Exports and Imports

(Differences in percent per year)

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|
| **I. Export Indexes** | | | | | | |
| Formula for lower-level aggregates | | | | | | |
| Laspeyres | 100 | 104.1 | 104.1 | 102.5 | 99.4 | 98.2 |
| Törnqvist | 100 | 103.5 | 103.4 | 101.5 | 97.7 | 96.1 |
| Growth rate difference of Törnqvist from Laspeyres | | -0.58 | -0.16 | -0.33 | -0.66 | -0.43 |
| *Contribution of ICT goods to above difference* | | *-0.10* | *-0.18* | *-0.23* | *-0.41* | *-0.27* |
| **II. Import Indexes** | | | | | | |
| Formula for lower-level aggregates | | | | | | |
| Laspeyres | 100 | 103.2 | 101.6 | 99.0 | 95.1 | 93.5 |
| Törnqvist | 100 | 102.8 | 100.9 | 97.6 | 93.2 | 91.0 |
| Törnqvist, tariffs included in prices | 100 | 102.6 | 100.5 | 97.3 | 92.8 | 90.4 |
| Törnqvist, adjusted for tariffs and varieties | 100 | 102.6 | 99.8 | 95.7 | 90.3 | 87.5 |
| Growth rate difference from Laspeyres | | | | | | |
| Törnqvist | | -0.35 | -0.37 | -0.62 | -0.65 | -0.72 |
| Törnqvist, tariffs included in prices | | -0.55 | -0.48 | -0.60 | -0.82 | -0.87 |
| Törnqvist, adjusted for tariffs and varieties | | -0.60 | -1.14 | -1.54 | -1.77 | -1.41 |
| *Contribution of ICT goods to above difference* | | *-0.01* | *-0.33* | *-0.78* | *-0.59* | *-0.56* |
| **III. Terms of Trade** | | | | | | |
| Formula for lower-level aggregates | | | | | | |
| Laspeyres | 100 | 100.9 | 102.5 | 103.6 | 104.5 | 104.9 |
| Törnqvist | 100 | 100.6 | 102.5 | 103.9 | 104.8 | 105.6 |
| Törnqvist, tariffs included in prices | 100 | 100.8 | 102.8 | 104.3 | 105.3 | 106.2 |
| Törnqvist adjusted for tariffs and varieties | 100 | 100.9 | 103.5 | 106.0 | 108.2 | 109.8 |
| Difference from Laspeyres in annual growth rate | | | | | | |
| Törnqvist | | -0.21 | 0.21 | 0.31 | 0.00 | 0.31 |
| Törnqvist, tariffs included in prices | | -0.02 | 0.33 | 0.29 | 0.17 | 0.46 |
| Törnqvist adjusted for tariffs and varieties | | 0.03 | 1.02 | 1.29 | 1.19 | 1.02 |
| *Contribution of ICT goods to above difference* | | *-0.09* | *0.15* | *0.58* | *0.19* | *0.33* |

**Notes:**
Lower-level aggregate are at the Enduse 5-digit (or in some cases 3-digit) level. These indexes are then aggregated using the Fisher Ideal formula to obtain the higher-level aggregates, shown here.

## Table 7: Fisher Price Indexes for GDP, Total Value Added, and Value Added of Private Business adjusted for Effects of lower-Level Törnqvist Indexes, Tariffs and Variety

| | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|---|
| **I. Price index for GDP** | | | | | | |
| Official (rebased to 1994=100) | 100 | 102.0 | 104.0 | 105.7 | 106.9 | 108.4 |
| After adjustment for Törnqvist formula, tariffs & variety | 100 | 102.1 | 104.1 | 106.0 | 107.3 | 108.9 |
| Growth rate difference | | 0.01 | 0.10 | 0.13 | 0.13 | 0.12 |
| **II. Price index for Total Value Added** | | | | | | |
| Growth rate difference | | 0.01 | 0.12 | 0.15 | 0.15 | 0.13 |
| Difference in growth of real VA | | 0.00 | 0.10 | 0.16 | 0.14 | 0.12 |
| **III. Price Index for Private Business Value Added** | | | | | | |
| Official Laspeyres | 100 | 101.8 | 103.4 | 104.9 | 105.5 | 106.5 |
| Törnqvist formula without tariffs | 100 | 101.7 | 103.4 | 104.9 | 105.6 | 106.7 |
| Törnqvist formula with tariffs in prices and weights | 100 | 101.8 | 103.4 | 105.0 | 105.7 | 106.8 |
| Törnqvist formula, with tariffs and variety adjustment | 100 | 101.8 | 103.5 | 105.3 | 106.1 | 107.3 |
| Difference from Laspeyres in annual growth rate | | | | | | |
| Törnqvist | | -0.01 | 0.03 | 0.05 | 0.02 | 0.06 |
| Törnqvist, tariffs included in prices | | 0.01 | 0.07 | 0.06 | 0.06 | 0.09 |
| Törnqvist formula, with tariffs and variety adjustment | | 0.02 | 0.16 | 0.19 | 0.19 | 0.16 |
| Implied difference in growth rate of real output | | 0.01 | -0.13 | -0.20 | -0.18 | -0.15 |

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**Figure 1: U.S. Terms of Trade and Productivity**

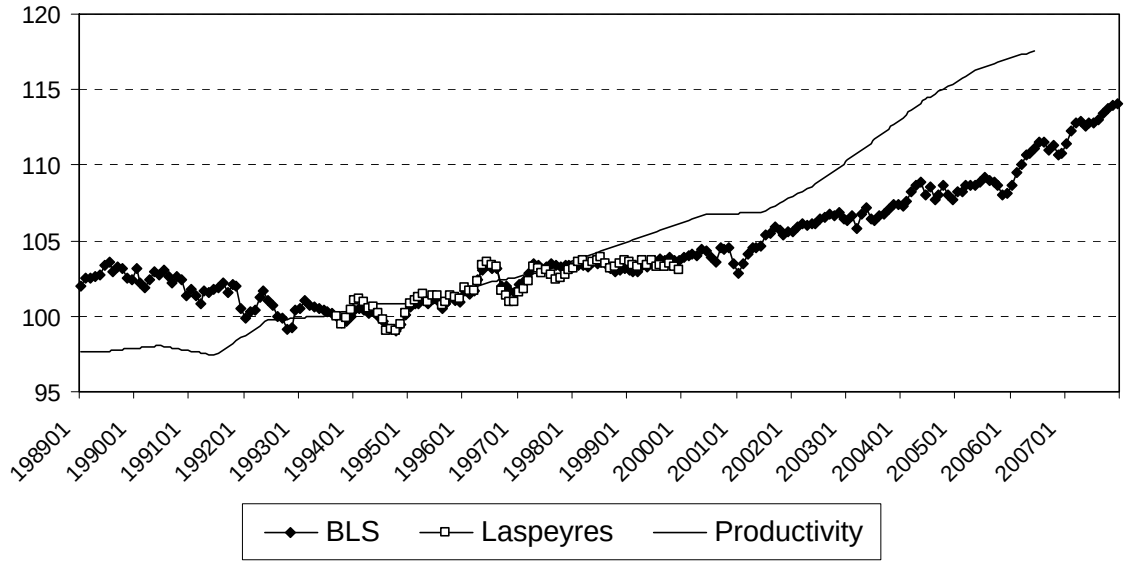



**Figure 2: Alternative Terms of Trade Indexes**

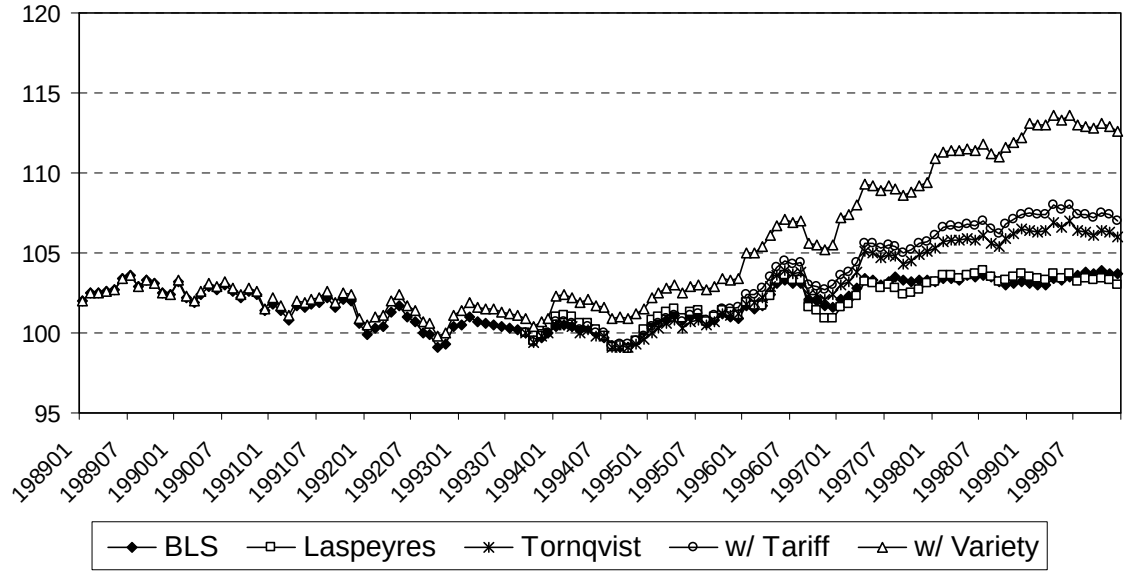


**Figure 3: Effect of a Tariff Reduction on an Imported Intermediate Input**

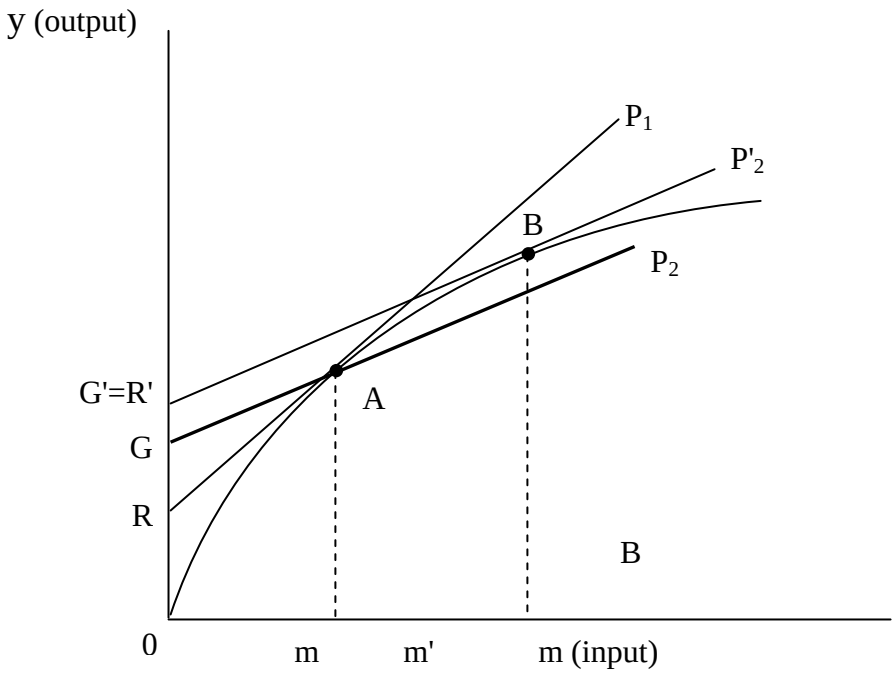



**Figure 4: Effect of a Tariff Reduction on an Imported Final Consumption Good**

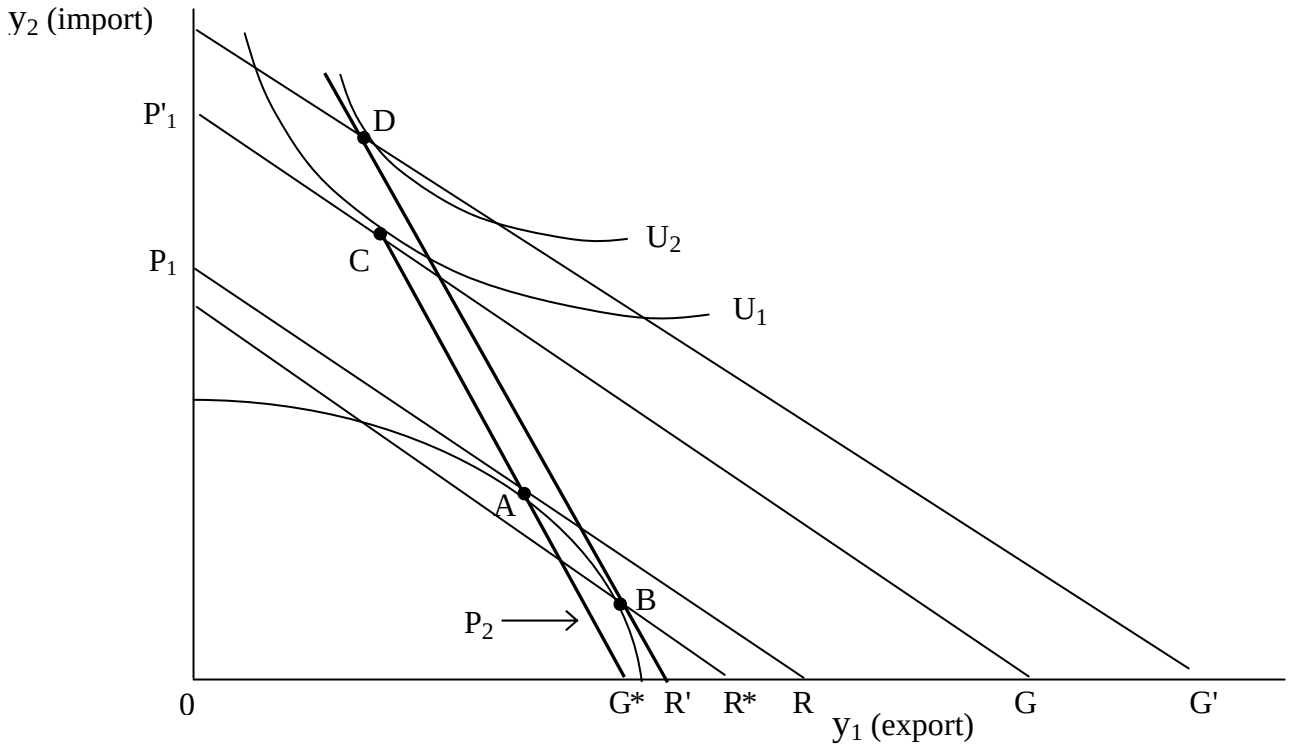


**Figure 5: Import Prices, Computers (21300)**

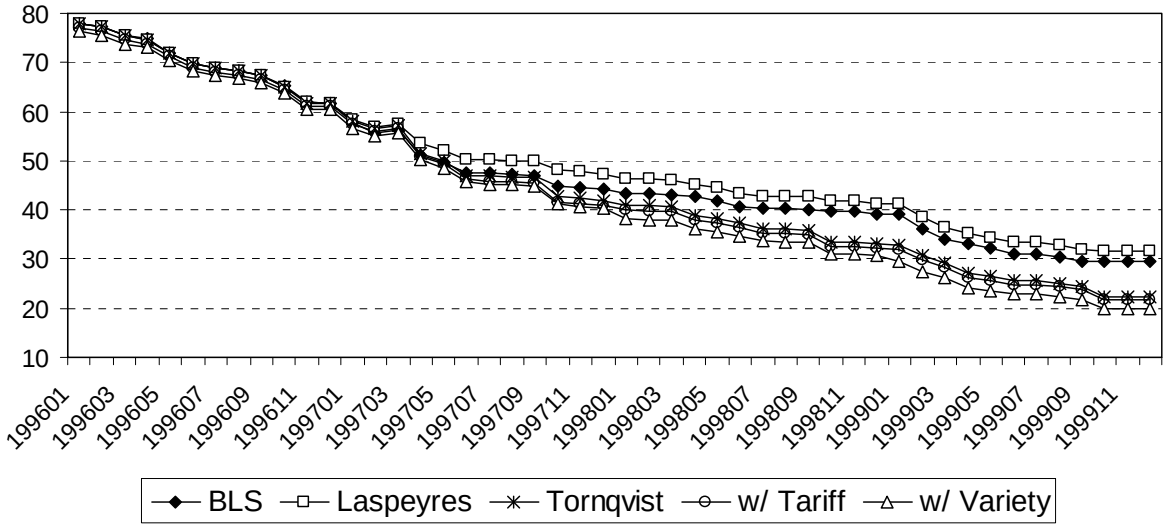



**Figure 6: Export Prices, Computers (21300)**

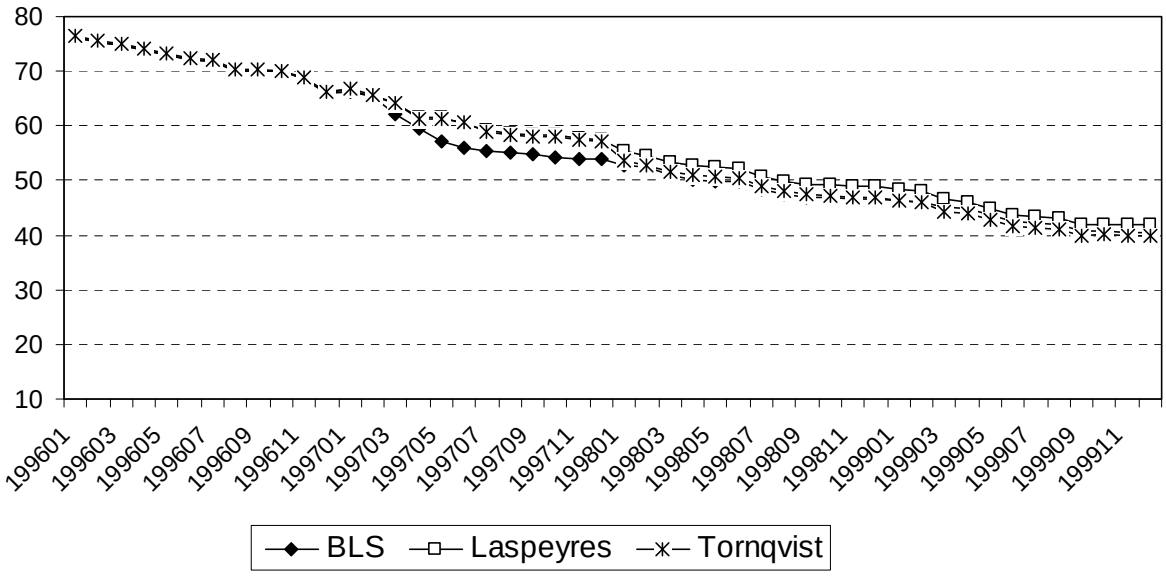


**Figure 7: Import Prices, Computer Accessories (21301)**

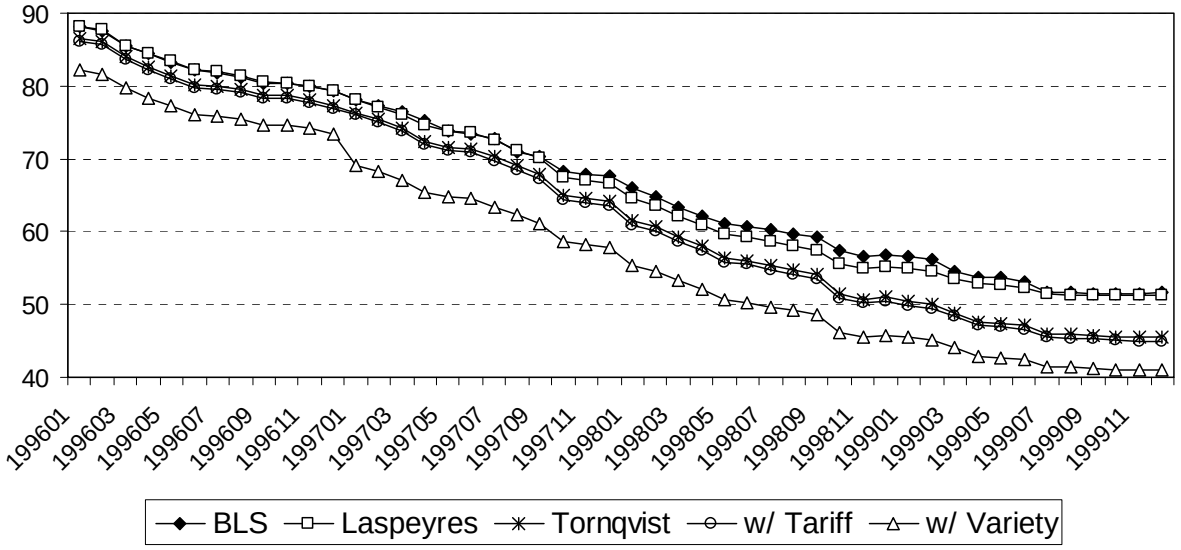



**Figure 8: Export Prices, Computer Accessories (21301)**

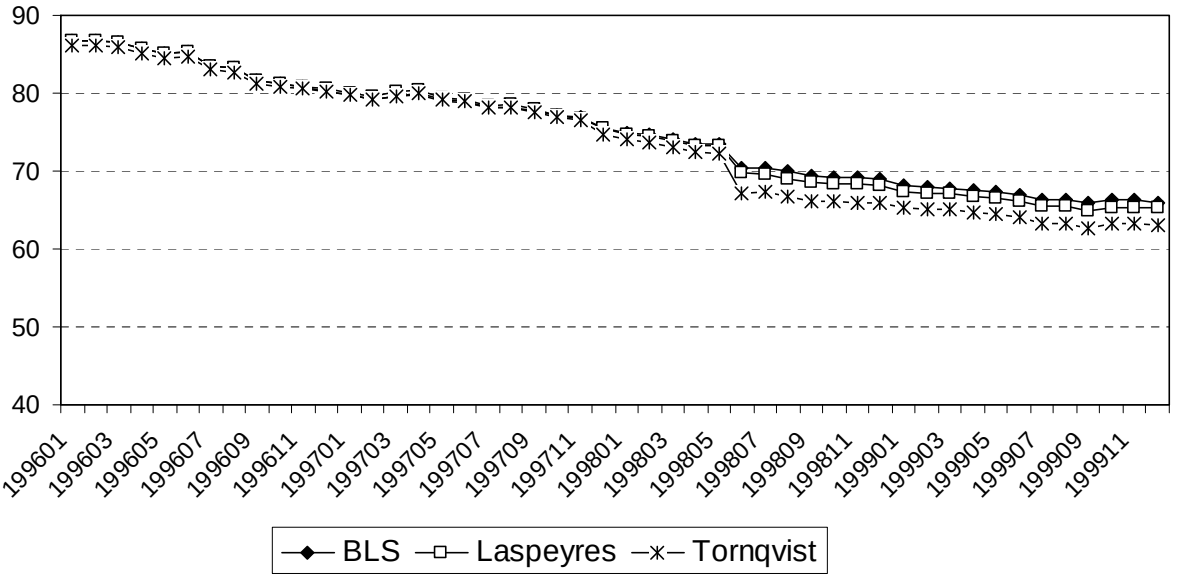


**Figure 9: Import Prices, Semiconductors (21320)**

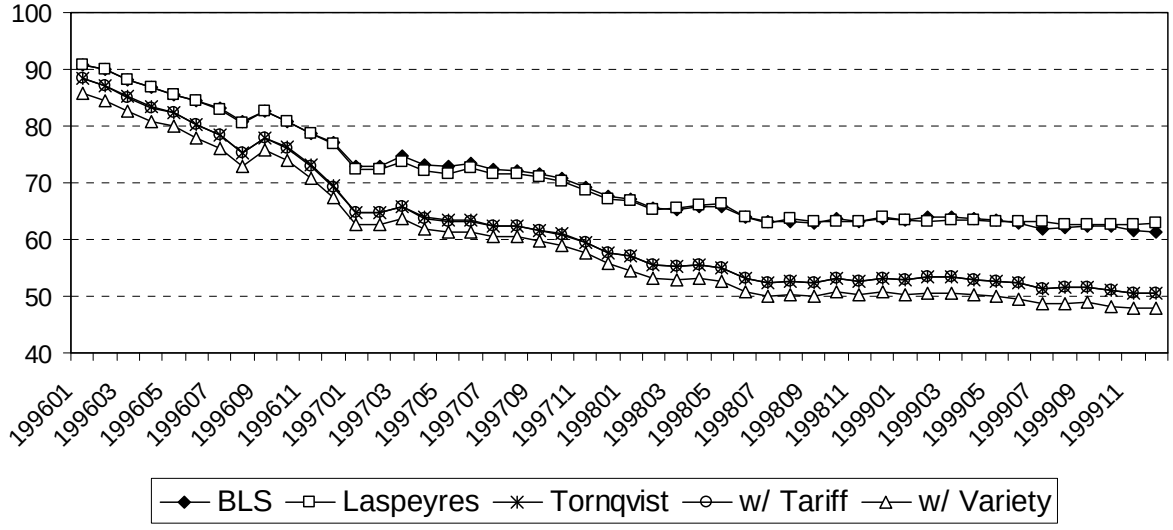



**Figure 10: Export Prices, Semiconductors (21320)**

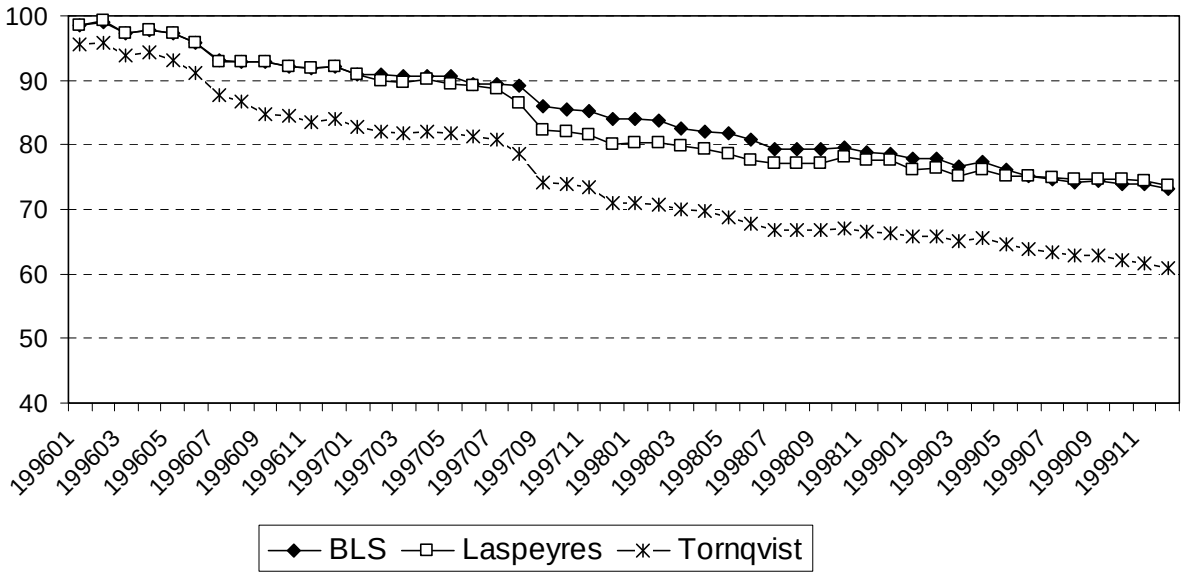
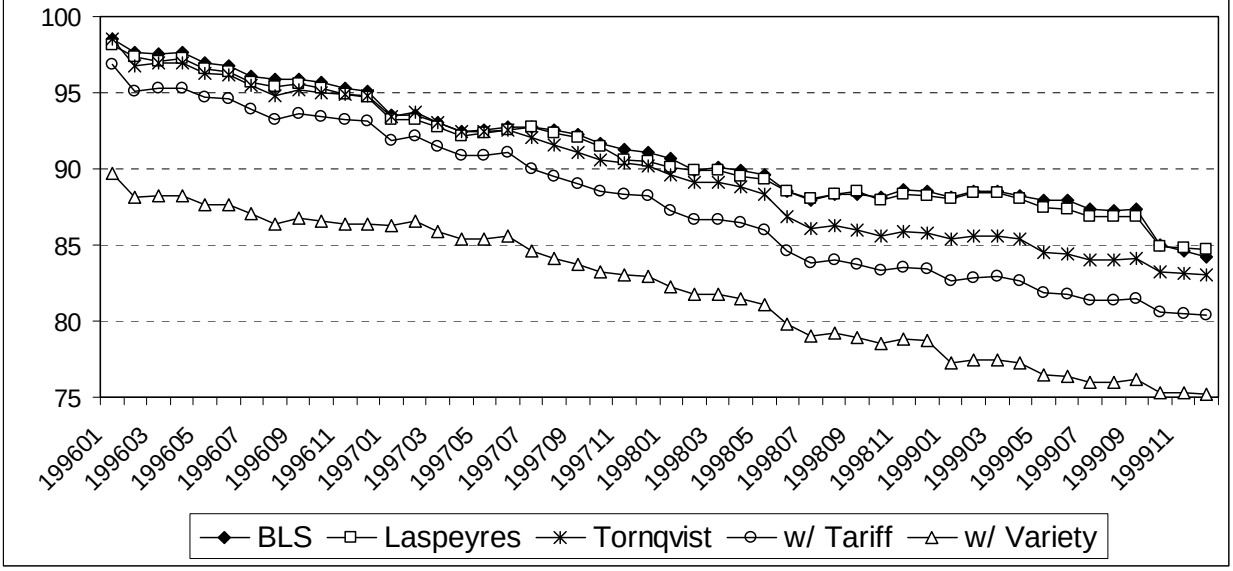


**Figure 11: Import Prices, Telecommunications (21400)**



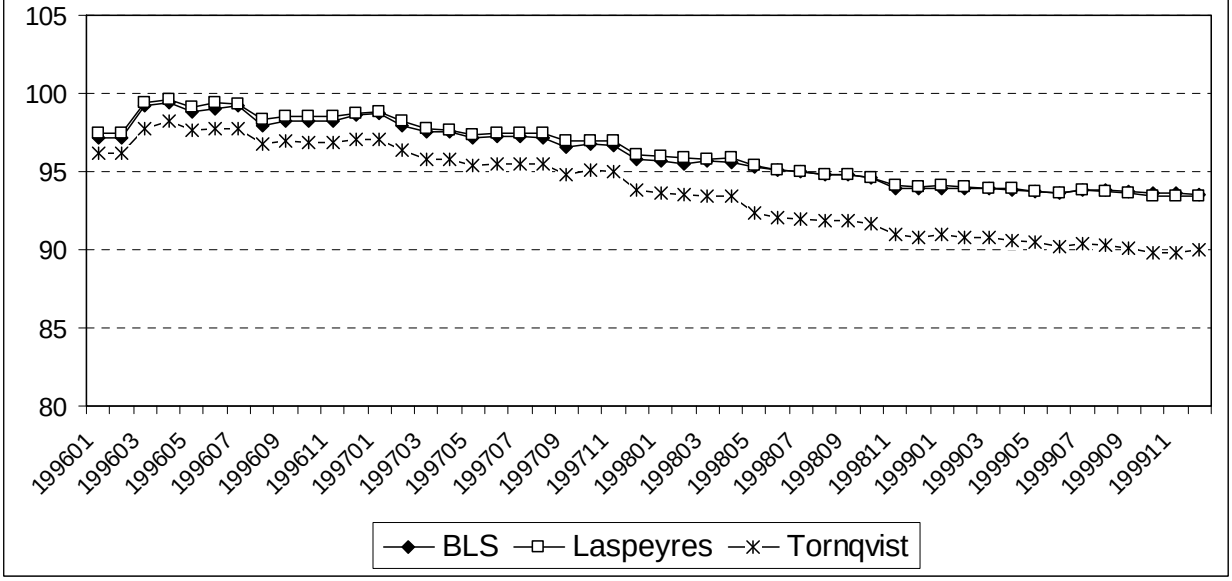


**Figure 12: Export Prices, Telecommunications (21400)**