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

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Abstract

After 1995, growth in productivity in the United States accelerated dramatically. That economy-wide growth is often attributed to declining prices for information technology (IT) goods, and therefore enhanced productivity growth in that sector. In this paper we investigate an alternative explanation for these IT price movements and for the apparent acceleration in U.S. productivity: gains in the U.S. terms of trade and tariff reductions, especially for IT products. The globalization of the IT sector deepened after 1995 thanks to the Information Technology Agreement of the WTO, which eliminated tariffs worldwide in hundreds of IT products. We demonstrate that this agreement led to magnified reduction in IT prices. Furthermore, we argue that conventionally measured import and export prices indexes are unlikely to accurately reflect these prices declines and this mismeasurement spills over into productivity calculations. From 1995 through 2006, the average growth rates of our alternative price indexes for U.S. imports are 1.5% per year lower than the growth rate of official price indexes. It follows that properly measured terms-of-trade gain can account for close to 0.2 percentage points per year, which is about 20% of the 1995-2006 apparent increase in productivity growth for the U.S. economy.

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1. Introduction

The single best measure of a country's average standard of living is its productivity: the value of output of goods and services a country produces per unit of factor inputs. The more workers produce, the more income they receive and the more they can consume. Higher productivity thus brings higher standards of living. Understanding the causes and proper measurement of productivity growth has long been a central research area in economics.

In the United States, since 1995 growth in aggregate labor productivity 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 1.37 percent per year. From 1995 through 2010 this rate accelerated to an average of 2.69 percent per year. [1] If sustained, this speed-up in U.S. productivity growth will carry dramatic implications for the U.S. economy. At the previous generation's average annual growth rate of 1.37 percent, average U.S. living standards were taking 51 years to double. Should the more-recent average annual growth rate of 2.69 percent persist, then average U.S. living standards would take just 26 years to double—a generation faster.

A large literature has in recent years analyzed this improvement in U.S. productivity growth. The declining prices of information technology (IT) products, which accelerated in the late 1990s, are often credited with key direct and indirect roles in the productivity speedup. For example, 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]

[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. In 2004-2008, U.S. productivity growth decelerated again, but in 2009 it resumed growing rapidly.
[2] Similarly, Oliner and Sichel (2000, p. 17) state that, "… we have interpreted the sharp decline in semiconductor prices after 1995 as signaling a pickup in that sector's TFP growth." Other prominent studies of the U.S. productivity acceleration include Baily and Lawrence (2001), Bosworth and Triplett (2000), Gordon (2000, 2003), Jorgenson and Stiroh (2000a,b), Nordhaus (2001, 2005), and Oliner and Sichel (2000, 2002).

In this paper, we argue that part of the apparent speed-up in U.S. productivity growth actually represented gains in the terms of trade and tariff reductions, especially for IT products. We first demonstrate that some of decline in IT prices was actually due to a multilateral tariff reduction under the World Trade Organization (WTO). Second, we argue that terms of trade improvements were under-measured in U.S. import and export price indexes and that tariffs should be included in import prices for productivity measurement purposes. These corrections imply that conventionally measured U.S. real output growth and productivity growth were overstated in the years after 1995.[3]

The starting point for our argument is the observation that on many measures, the global engagement of the U.S. IT industry deepened after 1995—precisely the period of accelerated IT price declines that have been interpreted as total factor productivity (TFP). Particularly important was the Information Technology Agreement, a comprehensive free-trade agreement that to date remains the only such agreement during the life of the WTO. Ratified in 1996 by dozens of countries accounting for nearly 95 percent of world IT trade, the ITA eliminated all world tariffs on hundreds of IT products in four stages from early 1997 through 2000. This timing suggests that the ITA, discussed in section 2, played an important role in the post-1995 trend in IT prices. In particular, for IT products made in multiple countries, a multilateral tariff reduction will lead to a magnified decline in their prices. Using data on the U.S. import prices of IT products, along with U.S. and foreign tariffs, we find strong evidence of such magnified price effects. This result is analogous to the magnified impact of tariff reductions on trade, as shown by Kei-Mu Yi (2003, 2010).

Evidence for the second part of our argument appears in Figure 1, which plots three series. The terms of trade based on indexes reported by the BLS is calculated as the ratio of the U.S.

[3] Related arguments about how substitution from domestic sources of supply to lower-priced imports can result in an overstatement of output and productivity growth are made by Houseman (2007) and several of the papers summarized in Houseman and Ryder (2010), including Houseman, Kurz, Lengermann and Mandel (2010) and Reinsdorf and Yuskavage (2010). That is a different effect from those that we examine in this paper, however.

export price index to the non-petroleum (to exclude the outsized role played by fluctuations in oil prices) import price index. The Laspeyres terms of trade index is based on Laspeyres indexes that we constructed from the price micro-data that BLS collected from importing and exporting firms for the period of September 1993 through December 2006. BLS uses a Laspeyres formula for its indexes, so our Laspeyres indexes replicate BLS methods using the micro data to which we had access for the analysis reported in this paper.[4] The third series in Figure 1, also from BLS, is U.S. multifactor productivity for the non-farm business sector. Its slope steepens in 1996, reflecting the fact that U.S. multifactor productivity growth rose from an average of 0.53 percent per year during 1987-1995 to 1.41 percent per year during 1996-2006.

The index of U.S. terms of trade shows a declining trend up until 1995 in Figure 1. But since 1995—at precisely the time that productivity growth picked up—U.S. terms of trade reversed and began rising, with a string of solid gains from 1995 through 2006. The average annual gain in the U.S. non-petroleum terms of trade from 1995 through 2006 was 1.0%, implying a cumulative gain nearly as large as the 15% deterioration in terms of trade from the petroleum price shocks in 1973-74 and 1979-80. The fact that U.S. terms of trade began to improve precisely when productivity accelerated suggests a connection between the two.

What this link might be, however, is not immediately clear from standard theories of trade and growth. By definition, direct, first-order effects from price changes are excluded from the concept of productivity change. Consistent with this, Kehoe and Ruhl (2008) 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 (2008) from a

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[4] Our Laspeyres terms-of-trade index does not exactly match the one constructed from published BLS indexes because we have incomplete data for some industries. But the difference is immaterial.

one-sector to a multi-sector model and similarly consider tariff reductions. In our multi-good setting, tariff reductions and changes in the terms of trade have a second-order impact on GDP and productivity.

Yet if the terms of trade are *mismeasured*, the story is critically different. Unmeasured changes in the terms of trade have a first-order impact on conventionally measured productivity growth. In particular, if the reduction in import prices is understated then, other things being equal, conventionally measured productivity growth will be correspondingly overstated.

There are three reasons why the U.S. terms of trade may be mismeasured for purposes of identifying U.S. productivity growth. First, as already noted, the BLS import and export price indexes use a Laspeyres formula rather than a superlative formula. Second, the BLS import indexes—which the Bureau of Economic Analysis (BEA) uses to deflate imports—measure import prices *free of tariffs*, and imports are likewise valued excluding duties in the calculation of GDP. The relevant import prices facing firms do, however, include these trade barriers. And third, the BLS import price index does not account for increases in the variety of imports coming from new supplying countries. As demonstrated by work including Feenstra (1994), Hummels and Klenow (2006), and Broda and Weinstein (2006), the economic impact of expanding varieties is large and therefore critical to account for. In section 4 we construct price indexes that correct for all three of these errors.

In terms of Figure 1, this key part of our overall argument is that the actual improvement in U.S. terms of trade was even higher than the improvement implied by the indexes reported by BLS. To preview our main results, Figure 2 shows several alternative terms-of-trade indexes based on our calculations in this paper. We repeat from Figure 1 the BLS and our computed Laspeyres indexes and then show three others: (i) an exact Törnqvist index for the terms of trade; (ii) the

Törnqvist index that also incorporates tariffs into the import prices; (iii) the Törnqvist index that incorporates both tariffs and import variety.[5]

The key message of Figure 2 is that, corrected for these three measurement errors, actual U.S. terms of trade were rising much faster that officially reported. The cumulative impact of these three adjustments means that the rise to just December 1999 in the Törnqvist index that incorporates tariffs and variety was nearly equal to the cumulative rise in the Laspeyres index all the way to December 2006 (compare Figures 1 and 2). While the Laspeyres terms of trade constructed from BLS export and import price indexes rose about 0.9% per year over 1995-2006, the Törnqvist index incorporating tariffs and import variety rose more than twice as fast, at 2.2% per year over the same period. The true terms-of-trade gain for the United States since 1995 has been much higher than indicated by official price indexes.

The corrected terms-of-trade indexes in Figure 2 cannot, however, be used to infer the amount by which unmeasured terms-of-trade gains have altered reported U.S. productivity growth. They are corrected versions of BLS's *aggregate* export and import indexes, but BEA's measures of real output growth—which drive the calculations of productivity growth—use *detailed* industry export and import price indexes, primarily the five-digit Enduse indexes produced by BLS, to deflate disaggregated measures of exports and imports. To combine the detailed indexes into a deflator for GDP, BEA uses weights based on the composition of GDP and it uses a chained Fisher formula, not a Laspeyres formula.

Accordingly, to estimate the impact of mismeasured terms of trade on reported productivity growth, in section 5 we construct complete sets of corrected Enduse export and

[5] 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 after 1995, however, just like our other two adjustments.

import price indexes at the 5-digit level (or the 3-digit level in a few cases where the 5-digit level of detail is not published by BLS). For exports, we construct two sets of detailed indexes, one containing Laspeyres indexes that mimic official BLS indexes (as a benchmark), and another containing Törnqvist indexes. For non-petroleum imports, we construct four sets of detailed indexes: Laspeyres indexes that mimic official BLS indexes; Törnqvist indexes; Törnqvist indexes including tariffs; and Törnqvist indexes including tariffs and a correction for net entry of new varieties. We then use a chained Fisher index formula to calculate two alternative indexes for exports and four alternative indexes for non-petroleum imports. From these indexes, we calculate four versions of the deflator for GDP, a benchmark version based on our detailed Laspeyres indexes and three alternative versions based on the detailed Törnqvist indexes.[6] Also, because the government component of GDP is excluded from official measures of productivity, we calculate the deflator for a subset of GDP that excludes government, gross value added of private business.[7]

Corrections to deflators for GDP and its subsets imply corrections to measures of real output growth, which, in turn, imply corrections to measures of productivity growth. By comparing productivity growth calculated from our three alternative corrected price indexes with that obtained with our reconstructed official BLS indexes, we thus can estimate the portion of conventionally reported U.S. productivity growth that was actually due to unmeasured gains in terms of trade and declines in tariffs. Our corrected price deflators rise faster than the official deflator, and so our corrected real output and productivity growth are lower. Our preferred

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[6] As explained in Diewert (1978), Fisher indexes lack the property of consistency in aggregation in an exact sense, but they *are* approximately consistent in aggregation. This means that Fisher index for GDP is nearly, but not precisely, equal to a combination of the Fisher indexes for each of the mid-level aggregates of C, I, G, X and M.

[7] 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. BLS measures the output of private business by its value added because including imported intermediates in inputs instead of netting them out of the output was found to have little effect on the TFP estimates.(Gullikson and Harper, 1999, p. 50 and fn 29).

estimates are that properly measured terms-of-trade gains and tariff reductions account for close to 0.2 percentage points—about 20%—of the reported 1996-2006 increase in U.S. productivity growth. Section 6 concludes.

2. The Information Technology Agreement

Under the auspices of the World Trade Organization (WTO), the Information Technology Agreement (ITA) committed signatory countries to eliminate all tariffs on a wide range of nearly 200 IT 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. [8] Some developing countries were granted permission to extend rate cuts beyond 2000, but no later than 2005. 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 virtually achieved that goal.

The tariff reductions over 1997-2000 experienced by a number of U.S. IT industries are shown in Table 1. The ITA tariff cuts are defined at the 8-digit level of the Harmonized System (HS) system, used to track import commodities. In Table 1, we indicate the percentage of import value within each industry that is 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 1 also includes the information for several other industries where more than 50% of import value was covered by the ITA, and industries such as business machines and equipment, and measuring, testing, and control instruments, where less than 50% of the import value was affected by the ITA agreement.[9]

In Table 1 we also show the average tariffs at the beginning of 1997, before the ITA was implemented, and in 2000, when it was concluded. Clearly, U.S. tariffs in these industries even before the ITA agreement were low: average tariffs were between 1 and 4% 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 had a multiplied impact on lowering their import prices and costs. Yi (2003, 2010) formally models how trade-barrier reductions can trigger magnified responses in trade volumes in the presence of cross-border production networks like those so central to IT. We investigate the analogous effect

[8] 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.
[9] Omitted from Table 1 are industries where less than 10% of imports are covered by the ITA.

for import prices in the following section, and indeed, we find that the estimated effect of the ITA agreement on U.S. import prices is much larger than that of the direct decrease in tariffs.

Impact of the ITA on Import Prices

To determine how the tariffs cuts under the ITA affected import prices, we construct a geometric index for tariffs in industry i, denoted by $Tar_i^{t-1,t}$, as:

$$Tar_i^{t-1,t} = \prod_{j \in J_i} \left(\frac{1+\tau_{ij}^t}{1+\tau_{ij}^{t-1}} \right)^{w_{mij}^t},$$

where τ_{ij}^t denotes the *ad valorem* U.S. tariff rate for product i coming from country j in month t, and w_{mij}^t denotes the share of import expenditure for good i on country j. In practice we use annual data for imports so that w_{mij}^t differs by year rather than by month. In addition, we construct a geometric index of exchange rates in Enduse industry i, $Exch_i^{t-1,t}$, as a weighted average of the exchange rate times the producer price indexes (PPI) for U.S. trading partners. These are combined with Laspeyres month-to-month indexes of import and export prices, $P_{miL}^{t-1,t}$, $P_{xiL}^{t-1,t}$, whose construction mimics that used by the BLS (as discussed in section 4) except that the import price indexes are tariff-inclusive.

These indexes are cumulated from September 1993 through December 2006 to obtain $P_{miL}^{0,t}$, $P_{xiL}^{0,t}$, $Tar_i^{0,t}$ and $Exch_i^{0,t}$. We use them in the following pass-through regression:

$$\ln P_{miL}^{0,t} = \alpha_{i0} + \sum_{k=1}^{3} \alpha_k \delta_k^t + \beta \ln Tar_i^{0,t} + \sum_{l=0}^{6} \beta_l \ln Exch_i^{0,t-l} + \gamma Z_i^t + \varepsilon_{it},$$

where: α_{i0} is a fixed-effect for each industry, δ_k^t are three indicator variables for the stages of the ITA (i.e. July 1997, January 1998 and January 1999) and Z_i^t denotes additional control variables. The prices of competing products belong in regressions of this type, so our first control variable is the U.S. export price index for industry i, $P_{xiL}^{0,t}$. In addition, Bergin and Feenstra (2007) have recently shown that the share of imports coming from countries with fixed exchange rates, and its interaction with the exchange rate, add explanatory power to pass-through regressions for the U.S., so we include those as control variables too.

Finally, we add controls for the impact of multistage international production on U.S. import prices. Yi (2003, 2010) demonstrates the importance of international vertical production linkages for explaining why observed international trade flows are substantially larger than what standard theory would predict. Here we extend his reasoning to apply to trade *prices*; goods crossing borders multiple times at sequential stages of production will amplify the impact of a multilateral liberalization by reducing the cost of imported intermediate inputs for downstream firms. This result is shown from equations (5) and (6) in Yi (2010). In a two-stage production process where intermediates are exported and final goods imported, the pass-through of a symmetric iceberg trade cost, $(1+\tau)$, to import prices is $(1+\theta)(1+\tau)$ log points, where θ indexes the share of imported intermediates in final good production. If a third stage is present, the pass-through multiplier for trade costs rises to $(1+\theta+\theta^2)$. Therefore, as the number of stages grows large, the pass-through multiplier for vertical integration approaches $1/(1-\theta)$.[10]

To capture these ideas in our pass-through regression, we first include *foreign tariffs in the same industry* within the pass-through regression.[11] The results are shown in columns (1)–(3) of Table 2, which uses $\text{Tar}_i^{0,t}$ as the U.S. tariff and a weighted average of foreign tariffs. The first regression in is run over those industries where 100% of the import commodities are covered by

[10] Incidentally, this multiplier looks similar to the border effect in the two-stage model of $(1+\theta)/(1-\theta)$ derived by Yi (2010), but arises for a different reason.

[11] We use the MFN ad-valorem applied tariff rates for U.S. trading partners from TRAINS, aggregated annually from the 6-digit HS schedule to 5-digit Enduse industries and across U.S. trade partners. For the ITA industries, the tariffs available on the WTO webpage were more accurate and were used in place of the TRAINS tariffs.

the ITA (denoted by ITA = 1); from Table 1, these industries are computers, peripherals and semiconductors. The second regression is run over those industries where 1 – 99% of the import value covered by the ITA (0 < ITA < 1), and the third regression is run over a control group of industries that include no ITA commodities (ITA=0).[12]

Looking first at the regression for ITA = 1, 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 nearly 20%. The tariff variable itself has a "pass-through" coefficient of 13.3, which is extremely large compared to what is normally found and indicates that the tariff declines have a highly magnified effect on lowering the import prices.[13] The foreign tariff has a coefficient of 4.15, which is also very large. Our expectation from the two-stage production model of Yi, discussed above, is that the total pass-through of a symmetric tariff cut of one percentage point would be (1+θ) percentage points, which we can separate as coefficients of 1 on the U.S. tariff and θ on the foreign tariff. Obviously, our results in column (1) indicate a *much larger* impact of the ITA tariff cuts.

Column (2) of Table 2 reports the pass-through regression run over industries with intermediate levels of import value covered by ITA products (i.e., 0 < ITA < 1). This regression indicates a U.S. tariff pass-through coefficient of 2.4, and 0.32 for the foreign tariff. These estimates are still larger than, though more in line with, Yi's two-stage model (i.e. coefficients of 1 on the U.S. tariff and θ on the foreign tariff again). Column (3) reports the pass-through regression for a control group of primarily capital and consumer goods industries that do not include any commodities affected by the ITA tariff cuts. For these industries, we find a U.S. tariff coefficient

[12] The control group of industries used in the final regressions includes capital goods (Enduse 2), automobiles and parts (Enduse 3), consumer goods (Enduse 4) and chemicals (Enduse 12).
[13] In the absence of the foreign country control variable, the coefficient on the tariff variable is 19.4.

of 0.99, which is insignificantly different from unity, while the foreign tariff is not significant at all.[14]

One reason that the pass-through coefficients for the ITA=1 industries are so high may be that these goods are subject to more stages of international production than two: components might cross borders multiple times. If so, a 1 percent symmetric tariff cut would have a cumulative impact on the price of $1/(1–\theta)$ percent, where θ is the share of imported intermediate inputs. The coefficient θ applies to the foreign country in Yi's model, but the variable available to us is the share of imported intermediate inputs for the U.S. described in Feenstra and Hanson (1999). Recognizing that a θ computed with U.S. data is not necessarily applicable to foreign countries, we do an analogous calculation of θ using the 2000 Chinese input-output table, which distinguishes ordinary and processing imports to China. Our preferred specification, reported in columns (4)–(6), uses a weighted average of the Chinese and U.S. values of θ (using the U.S. import shares of ordinary and processed Chinese goods, and non-Chinese goods, by industry), and multiplies both the U.S. tariff and the foreign tariff by $1/(1–\theta)$ in each Enduse industry.

The results for the ITA=1 industries in column (4) show that the pass-though coefficient of U.S. tariffs comes down to 1.5, while the coefficient on the foreign tariff is 0.7 (both these tariffs are multiplied by $1/(1–\theta)$). These are much more reasonable values for pass-through coefficients, with the coefficient on the U.S. tariff insignificantly different from unity. For the other ITA industries in column (5), we find a pass-though of the U.S. tariff of almost exactly unity, and a very small effect for the foreign tariff. Finally, for the control group of industries in column (6),

[14] We have also estimated the price regression for subsets of the control group. For automobiles and parts (Enduse 3), and for consumer goods (Enduse 4), the linear combination of the tariff coefficient and partner tariff coefficient is insignificantly different from unity. For capital goods, that linear combination is insignificantly different from 1.5; this pass-through would be exactly the prediction of the Yi model with θ =0.5. The only Enduse category outside the ITA industries that shows consistently higher tariff and partner tariff coefficients is Enduse 12500, which is chemicals. However, not including chemicals in the control group has only slight effects on the tariff coefficient.

the pass-through from the U.S. tariff is 0.72, which is somewhat lower than expected but not that unusual and, again, we find very small foreign tariff effects.

Thus, by controlling for many stages of production using $1/(1-\theta)$ we obtain very reasonable estimates for the ITA=1 industries, without affecting the other industries too much. These findings support our hypothesis that the multi-stage nature of production in high-tech industries is responsible for the magnified impact of the tariff cuts in reducing import prices. Despite the fact that U.S. tariffs were low, the global nature of the ITA resulted in significant reductions in U.S. high-tech prices. This result is shown in last column of Table 1, where we have computed the implied change in U.S. import prices for high-tech products due to the ITA. We do so by comparing actual import prices with an estimate of counterfactual prices had the ITA *not* occurred, what we call a "non-ITA" price index. This latter series is constructed using the pass-through coefficients in columns (1) and (2) of Table 2 and by holding the tariff-related variables constant at their pre-ITA levels.[15] The resulting predicted values are our best estimate of the counterfactual import prices that would have existed had the ITA not been implemented.[16] The last column of Table 1 reports the percentage difference at the end of our sample period between the published import prices and our calculated hypothetical non-ITA import prices. Tariffs played a key role in lowering U.S. import prices for high-tech goods: the ITA contributed 16 and 24 percent, respectively, to the decline in computer and computer accessory prices, and large amounts to several other Enduse industries.

3. Measurement of Productivity Growth with International Trade

[15] To facilitate comparison with the BLS published series, we set the non-ITA series equal to the BLS import prices up until June 1997 and use the predicted values of the pass-through regression to extend the index thereafter.

[16] An alternative formulation of this counterfactual would use columns (4) and (5) instead of columns (1) and (2). However, the difference between those two series turns out to be small and does not materially affect our results.

We have seen in the previous section that tariffs on imported IT products fell during the period covered by the ITA. In this section we describe how to account for such declines in tariffs in the measurement of total factor productivity (TFP) at an economy-wide level, and we consider additional sources of mismeasurement of TFP arising from the deflators for exports and imports. 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. To outline the notation, suppose there are 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 τ_{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 τ^t. Then the revenue function for the economy is:

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

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.

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.[17] 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.

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:

Proposition 1

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

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[17] Assuming that tariffs are the only tax on products, $R^t(P^t+T^t, v^t)$ is the measure of aggregate output known as "gross value added at basic prices" in the international guidelines for national accounts in the System of National Accounts or SNA and equation (3) is the production approach measure of GDP (United Nations *et al.*, 1993, paragraphs 6.235 and 6.237.) Following the SNA, we refer to $R^t(P^t+T^t, v^t)$ as the economy's total valued added. In contrast, BEA defines total gross value-added to *include* tariffs and other taxes on products, making it the same as GDP.

Proof: Because the derivative of the revenue function with respect to τ_{ij}^{t} is $-p_{mij}^{t}m_{ij}^{t}$, it follows that the first derivative of the GDP function with respect to τ_{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:

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

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 σ_i,

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

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 revenue is a translog function over the prices $\tilde{P}^t$ and endowments. We further assume that the parameters multiplying these prices in the translog revenue function are stable over time, but the coefficients multiplying endowments are allowed to change over time, reflecting technological change. It follows from Diewert and Morrison (1986) that:

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

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:

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

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

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

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 because 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:

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

where $G^t \equiv G^t(P^t, \tau^t, v^t)$ is nominal GDP, $P_E(P^{t-1},P^t,y^{t-1},y^t)$ is an exact GDP deflator over prices of final domestic demand, exports, and duty-free imports, and $Q_E(w^{t-1},w^t,v^{t-1},v^t)$ is an exact quantity index of primary factors. If the functional form for these 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 conventionally measured TFP in (8) is identical to "true" productivity growth in (6). However, measured 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 using components of the CPI, PPI and export and import price indexes obtained from BLS. The export and import component indexes are Laspeyres indexes and are duty-free.

To understand the impact of tariffs on the difference between "true" and 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). Yet even though the construction of conventional TFP in (8) is consistent in its treatment of tariffs, it is affected by tariffs because the *quantities* of outputs and inputs are chosen at tariff-distorted prices in (8) and hence 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

Proposition 2 states that the efficiency gain from eliminating tariffs — which is a movement around the production possibilities frontier — will incorrectly be attributed to TFP growth as measured by (8). But, in addition to changes in tariffs, the level of tariffs can also interact with changes in prices to cause mismeasurement of productivity change. In particular, in the presence of tariffs, quantity responses to changes in the terms of trade can result efficiency gains or losses that are measured as changes in TFP. This is shown by the next proposition:

Proposition 3

Assume that technology and endowments do not change, so that $A^{t-1} = A^{t}$ in (4). Then $\tau^{t-1} \neq 0$ or $\tau^{t} \neq 0$ is a necessary condition for a change in prices to result in $TFP^{t} \neq 1$ in (8).

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.

The effects of tariffs on the measurement of productivity arise because the output concept that is measured by GDP uses tariff-free prices, while the output concept that is best-suited for measuring productivity change uses tariff-inclusive prices. For the United States and other industrial countries, tariffs and changes in tariffs — such as occurred under the ITA — are low. Thus, if the treatment of tariffs were the only problem in the measurement of productivity, we would expect the impact of the ITA on measured TFP to be small.

Yet when the price index $P_E(P^{t-1},P^{t},y^{t-1},y^{t})$ is *mismeasured,* additional measurement errors in TFP arise besides the omission of tariffs, and these need not be small. In particular, unmeasured changes in the terms of trade have a first-order impact on conventionally measured productivity growth. The U.S. import and export price indexes are subject to two sources of measurement error. First, as already noted, the industry-level BLS import and export prices indexes are Laspeyres indexes, so they are vulnerable to substitution bias. And second, the BLS import price index does not account for increases in the variety of imports coming from new supplying countries. 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 first-order.[18]

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[18] These first-order gains from import variety, as measured by Broda and Weinstein (2006), arise in the model of Krugman (1980) where an increase in import variety does not lead to any reduction in domestic variety. But in the

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. Denoting the Laspeyres export and import indexes from BLS by $P_{xiL}^{t-1,t}$ and $P_{miL}^{t-1,t}$, the deflator for GDP is:

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

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

$$-\sum_{i=1}^{N}\left(\frac{1}{2}\right)\left(\frac{\sum_{j=1}^{C} p_{mij}^{t-1}m_{ij}^{t-1}}{G^{t-1}}+\frac{\sum_{j=1}^{C} p_{mij}^{t}m_{ij}^{t}}{G^t}\right)\ln P_{miL}^{t-1,t}\ . \qquad (9)$$

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), the difference between measured and "true" TFP growth is:

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

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

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

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

Melitz (2003) model, Feenstra (2010) shows that the welfare gain from the increase in import variety exactly cancels with the welfare loss from the reduction in domestic variety. There is, however, still a first-order welfare gain from the improved selection of more productive firms into exporting.

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 the term on the first line of (10) is small. The term on the second line of (10) depends on the difference between the "true" index of export prices $(p_{xi}^t / p_{xi}^{t-1})$ and the Laspeyres index of export prices. If the Laspeyres index overstates the true index, as we shall find, that tends to make measured TFP less than the "true" productivity index. The reverse occurs on the import side, where upward bias in the Laspeyres price index $P_{miL}^{t-1,t}$ as compared to the "true" price index $(\tilde{p}_{mi}^t / \tilde{p}_{mi}^{t-1})$ leads to an upward bias in measured TFP. We find in the following sections that the differences between the "true" import price index $(\tilde{p}_{mi}^t / \tilde{p}_{mi}^{t-1})$ and the Laspeyres index can be substantial, especially for IT products, while the differences on the export side are 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 2006, 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 various 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:

$$P_{miG}^{t-1,t} \equiv \prod_{j \in J_i} \left(\frac{p_{mij}^t (1+\tau_{ij}^t)}{p_{mij}^{t-1}(1+\tau_{ij}^{t-1})} \right)^{w_{mij}^t}, \tag{13}$$

where $P_{miG}^{t-1,t}$ is the "geometric" index due to Sato (1977) and Vartia (1977), and uses the weights w_{mij}^t 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:

$$s_{mij}^t = \frac{p_{mij}^t (1+\tau_{ij}^t) m_{ij}^t}{\sum_{i \in J_i} p_{mij}^t (1+\tau_{ij}^t) m_{ij}^t}, \text{ with } w_{mij}^t \equiv \left(\frac{s_{mij}^t - s_{mij}^{t-1}}{\ln s_{mij}^t - \ln s_{mij}^{t-1}} \right) \Bigg/ \sum_{i \in J_i} \left(\frac{s_{mij}^t - s_{mij}^{t-1}}{\ln s_{mij}^t - \ln s_{mij}^{t-1}} \right). \tag{14}$$

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 may sell good i or other supplying countries may exit, we need to extend the Sato-Vartia formula to account for effects of new and disappearing countries. A formula to do this is derived in Feenstra (1994) for the CES model with □> 1. Suppose that the set of countries supplying product i in period t, $j \in J_i^t$, has a non-empty intersection with a base period 0 set, J_i^0. We denote this intersection by $J_i \equiv J_i^0 \cap J_i^t \neq \emptyset$. Then define the term λ_{mi}^t as the value of imports in period t from countries also supplying product i in period 0, relative to the total imports of product i in period t:

$$\lambda_{mi}^t \equiv \frac{\sum_{j \in J_i} p_{mij}^t m_{ij}^t}{\sum_{j \in J_i^t} p_{mij}^t m_{ij}^t} \leq 1 . \tag{15}$$

The term λ_{mi}^t □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, λ_{mi}^t can be interpreted as *one minus the share of period t expenditure on "new" selling countries (not in the set J_i).* The greater the market share of the new selling countries in period t, the lower the value of λ_{mi}^t. The corresponding term for period t-1, λ_{mi}^{t-1}, equals period t-1 expenditure on the goods in J_i relative to the total expenditure, or one minus the share of expenditure on new countries. Then the ratio of CES price aggregates that includes the effect of net entry of new supplying countries can be expressed as:

$$\left(\frac{\tilde{p}_{mi}^t}{\tilde{p}_{mi}^{t-1}}\right) = P_{miG}^{t-1,t}\left(\frac{\lambda_{mi}^t}{\lambda_{mi}^{t-1}}\right)^{1/(\sigma_i-1)}, \tag{16}$$

where $P_{miG}^{t-1,t}$ is again the Sato-Vartia geometric index. As new supplying countries sell more, the effective price in (16) falls by an amount that depends on σ_i.

In applying equations (13) – (16) to the BLS price data, several issues arise. First, a true monthly Sato-Vartia price index $P_{miG}^{t-1,t}$ 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 $P_{miG}^{t-1,t}$ is still given by (13)-(14), but now w_{mij}^{t} reflects the *annual* import shares for Enduse industry i, which do not vary across months. The geometric indexes constructed in this way could equally well be called Törnqvist indexes — as we shall do — since with annual data there is no difference between the constant monthly values for $s_{mij}^{t-1} = s_{mij}^{t}$ and the weights w_{mij}^{t} in (14).[19]

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 (20), let h denote a 10-digit HS good and J_h^t denote the set of countries exporting that good to the U.S. in any month within the year. Then $J_h \equiv J_h^0 \cap J_h^t$ is the intersection of that set over year t and a base year 0, which is the first year that a HS code appears between 1989 and 1996.[20] We construct the λ-ratios in two steps: (a) we use (15) to construct $(\lambda_{mh}^{t} / \lambda_{mh}^{t-1})$ for each HS product h, and raise these to the power $1/(\sigma_h - 1)$ to reflect the elasticity of substitution between varieties (from Broda and Weinstein, 2006); (ii) then we take the geometric mean across products $h \in H_i$ within an Enduse industry i:

$$\Lambda_{mi}^{t} \equiv \prod_{h \in H_i} \left(\lambda_{mh}^{t} / \lambda_{mh}^{t-1}\right)^{w_{mhi}^{t}/(\sigma_h - 1)} . \qquad (17)$$

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[19] Normally the Törnqvist index uses the simple averages $(s_{mij}^{t-1} + s_{mij}^{t})/2$ for weights, but $s_{mij}^{t-1} = s_{mij}^{t}$ when using annual data. Then letting $s_{mij}^{t-1} \to s_{mij}^{t}$ in (20), we have $w_{mij}^{t} \to s_{mij}^{t}$, as can be shown using L'Hopitals rule.

[20] That is, for HS system codes that exist in 1989 we use that year as the base for constructing product variety. There was a major revision to the HS system in 1996, so for codes introduced between 1990 and 1996, we use the first year the code appeared as the base for constructing product variety. HS codes introduced after 1996 are not used.

Note that (17) is an *inverse* measure of import variety, because having new supplying countries will lead to a lower value in (17). Finally, in (16) the Törnqvist index $P_{miG}^{t-1,t}$ is multiplied by Λ_{mi}^{t} to obtain the price index corrected for variety.

Third, it is important to recognize that the measure of product variety we obtain is not invariant to the choice of base year, which we have assumed is the first year that an HS code appears between 1989 and 1996. That choice will ensure that all countries who first supply in an HS category after 1989 will be included in the term λ_{mh}^{t} every year, and are therefore being treated as having *entirely new products every year.* As explained by Feenstra (1994, Prop. 1), these countries can have shifting taste parameters – or shifting quality – for their products every year, and our construction of the CES index is still exact. Allowing for shifting quality in this way is especially important for IT products. In contrast, the countries who are already supplying in an HS category in the first year it appears are assumed to have constant taste parameters and quality. By choosing an early base year we are therefore allowing for the most countries to have changing quality for their products, which was also the approach taken by Broda and Weinstein (2006).[21]

Having obtained the import price indexes for each 5-digit Enduse industry, we do the same for exports, but this time there is no correction for variety.[22] We denote the Törnqvist export price indexes by $P_{xiG}^{t-1,t}$, which are used in place of $(p_{xi}^{t} / p_{xi}^{t-1})$ in (10). The import and export price indexes are constructed for all 5-digit Enduse industries from September 1993 – December 2006. In Figures 1 and 2 we displayed the terms of trade constructed from the Laspeyres and Törnqvist

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[21] Broda and Weinstein used 1972 as the base year for the Tariff Schedule of the U.S. (TSUSA) system, and 1990 for the Harmonized system, while omitting 1989 due to the unification of Germany in that year.

[22] Feenstra and Kee (2008) and Feenstra (2010) argue that new export varieties should be modeled as having a rise in their price from a low price, where supply is zero, to a higher price. Therefore, adjusting export prices for increased variety leads to an increase in the effective export price index and an increase in the implied terms of trade. However, this result assumes that the entry of new export varieties is driven by shifts in foreign demand, not domestic

indexes for aggregate export and import price indexes. In Figure 3–10 we show the import and export indexes for the various IT industries, normalized to 100 in September 1993 (except for computers, which begins in 1994).

In Figure 3 we show the BLS, Laspeyres, non-ITA Laspeyres (as defined in Section 2), and Törnqvist indexes (with adjustments for tariffs and variety) for imports of Computers, Enduse 21300. Our Laspeyres index differs only slightly from the published BLS price index, due to missing data and concordances that are not fully accurate, but the differences seem small enough to proceed. The non-ITA series, which projects a path for import prices holding tariff variables constant after June 1997, lies well above the published series; this gap demonstrates the importance the ITA played in lowering high-tech prices relative to the hypothetical world with no ITA. The tariff-inclusive Törnqvist index is about 7 percentage points below the Laspeyres by the end of the sample, though since actual tariff declines were small, the vast majority of the difference is accounted for by the alternative index formula. The impact of variety is to reduce the price index by a modest 1% through 2006. On the export side, in Figure 4 the BLS index, Laspeyres and Törnqvist are all very close, deviating only slightly over the sample period.

The greater upward bias of the Laspeyres index in the case of imports can be explained by the difference between the way that substitution behavior affects the import index and the way that it affects the export index. For imports, cost-minimizing behavior by U.S. buyers tends to raise the relative quantities of the items with the smallest price indexes, causing the superlative Törnqvist index to be below the Laspeyres index. For exports, revenue-maximizing behavior of U.S. producers responding to shocks in foreign demand tends to raise the relative quantities of the items

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productivity gains. Because domestic productivity gains are clearly an important driver of new export varieties, we do not pursue the adjustment for export varieties here.

with the largest price increases, *raising* the relative position of the Törnqvist index.[23] Indeed, if shocks to foreign demand and falling foreign tariffs were the only drivers of changes in the composition of U.S. exports, we could expect to find the Laspeyres export index to be *below* its Törnqvist counterpart, but the presence of other factors, including shocks to domestic supply, means that producer substitution behavior just makes the difference between the Laspeyres index and the Törnqvist index smaller without reversing its sign.

In Figure 5 we show the import price indexes for Computer Accessories (Enduse 21301). In this case, the non-ITA Laspeyres index lies 24 percentage points above the Laspeyres by the end of the sample, while the tariff-inclusive Törnqvist index is about 9 percentage points below the Laspeyres. Further adjustment for variety is small, so that the Törnqvist index inclusive of tariffs and variety is 11 percentage points below the Laspeyres by December 2006. For exports in Figure 6, the Törnqvist index has a relatively large drop in June 1998, which appears 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 (19).

Turning to Semiconductors (Enduse 3120) in Figures 7 and 8, for imports we again see that the tariff-inclusive Törnqvist index is about 13 percentage points below the Laspeyres by the end of the period. Though the effects of the ITA are more modest than for computers, the impact of variety is significant, reducing the price index by 5 percentage points over the course of the sample. For exports, we see that the Törnqvist index lies substantially below the Laspeyres index. In this case, it appears that the conventional demand-side upward bias of the Laspeyres index dominates, as buyers of U.S. exports substitute away from goods whose relative prices have gone

[23] Varian (1984) presents the theory of the reverse direction of substitution bias in a producer's index from the more familiar substitution bias of a consumer's index, which is covered in Varian (1982).

up. This demand-side substitution on exports did not occurs for Computers, where the Törnqvist export price index did not differ much from the Laspeyres. In general equilibrium, there can be either demand-side or supply-side substitution in the price and quantities, and so we should not be surprised that the Laspeyres bias in export price indexes can go in either direction; for the import price indexes, however, we generally find the upward bias expected for consumers.

Finally, in Figures 9 and 10 we show the indexes for Telecommunications (Enduse 21400). In this case the non-ITA prices were only slightly higher than the Laspeyres and the tariff-inclusive Törnqvist fell by 9 percentage points more, owing in part to a significant fall in tariffs over 1996-1999. The variety adjustment is especially substantial, leading to a reduction in the Törnqvist index by a factor of 0.93 in 1999 and accelerating to 0.67 in 2006. On the export side, we see that the Törnqvist index is below the Laspeyres, which is the same pattern that occurred in Semiconductors and in the later periods for Computer Accessories.

To summarize the results from these four IT 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. The contribution of the ITA to falling import prices is clear from these four industries as well. Absent the U.S. and global tariff cuts under the ITA, U.S. import prices would have fallen slower than they actually did. Finally, there is a further impact of rising variety on reducing the import price index. These additional impacts appear to be small in the Figures, but we show in the next section that variety has a sizable impact on the overall U.S. terms of trade and measures of productivity growth.

5. 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.[24] 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. Then, 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 also 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 with weights from the NIPAs to obtain deflators for merchandise exports and for non-petroleum merchandise imports.

Table 3 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 the Laspeyres index was used for all stages of aggregation (as shown in Figure 1). Using the Törnqvist formula to calculate the detailed indexes reduces the average growth rate in 1996-2006 of the aggregate Fisher export index by an average of 0.57 percent per year. The effect

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

of the use of the Törnqvist formula on the non-petroleum import price index is a bit larger, at 0.77 percent per year in 1996-2006, or 0.85 percent per year when tariffs are incorporated into the import indexes and weights. Finally, correcting the tariff-inclusive Törnqvist formula for growth in varieties results in a reduction of 1.47 percent per year in the average growth rate of the imports index compared with the baseline Laspeyres index in 1996-2006.

Annual terms of trade gains calculated from the Törnqvist export index and the variety-adjusted Törnqvist import index average almost 2 percent in the 1996-2006, compared to an average growth rate of the baseline Laspeyres terms of trade index of only about 1 percent per year. The difference between these growth rates, 0.93 percentage points, represents an estimate of the average amount of unmeasured gains in terms of trade that the U.S. enjoyed in the years of 1996-2006 (see the bottom panel of Table 3.)

Furthermore, the incremental changes in the estimate of terms of trade gains as we first switch from the Laspeyres formula to a Törnqvist formula, then incorporate tariffs in the import index, and finally correct for the growth of varieties, provide a decomposition of these unmeasured gains in terms of trade into three sources: the substitution bias of the Laspeyres index formula, the omission of tariffs from measures of import values and prices, and the unmeasured gains from growth of import varieties. Growth in import varieties is the largest source of gains that are missed by the conventional Laspeyres measure of terms of trade, accounting for 0.64 percentage points of 0.93 percent per year difference between the corrected terms of trade index and the Laspeyres terms of trade index. 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 conventional methods used to construct the official indexes.

The difference between the Törnqvist terms of trade with no adjustment for growth in import varieties, and the Laspeyres terms of trade grains is 0.21 percent with tariffs omitted from import prices, rising to 0.29 percent per year when tariffs are included in the Törnqvist index for imports. [25] The conventional Laspeyres terms of trade index under-estimates the gains in the terms of trade because the Laspeyres formula over-estimates import price growth more than it does export price growth, as was discussed in the previous section.[26]

Another way to analyze the sources of the change in the U.S. terms of trade and the underestimation of that change by the conventional Laspeyres measure is to look at the contributions of individual goods to these changes. IT goods play a substantial role in terms of trade gains no matter how these gains are measured. IT goods also contribute disproportionately to the difference between the Laspeyres and Törnqvist measures of prices, accounting, on average, for almost half of this difference in 1996-2006 in both the export case and the import case. Yet because their export side and import side effects largely offset each other, IT goods contribute only modestly to the underestimation of gains in terms of trade by the conventional measures. IT goods contribute about 0.25 percent per year in 1996-2006 to the Laspeyres measure of terms of trade growth and by about 0.35 percent per year to the corrected measure, so the unmeasured terms of trade gains attributable to IT goods are, on average, 0.11 percent per year.

As discussed earlier, an important reason that IT import prices were falling in recent years was the U.S. and global tariff cuts under the ITA. While the direct impact of ITA tariff reductions is not captured in BLS Laspeyres import price index, we demonstrated above that the pass-through of tariff reductions to import prices in these industries was substantial (see Table 1 and also Figures 3, 5, 7, and 9). In other words, the actual impact of the ITA *is* captured in the measured

[25] It is unusual to incorporate falling tariffs into a calculation of the terms of trade, but natural to do so in our context because we have shown in (6) that the tariff-inclusive prices should be used to deflate R^t .

Laspeyres import price indexes—and also in the import price indexes in Table 3 that account for various measurement problems. We can therefore calculate a hypothetical non-ITA Laspeyres import price index and compare it to the actual Laspeyres import price index reported in Table 3.

Table 4 shows this comparison, where we constructed the hypothetical non-ITA index like we did in replicating the BLS's actual index but with the important difference that for the Enduse categories covered by the ITA (i.e., categories reported in Table 1) we used not the reported import prices but rather our hypothetical non-ITA import prices constructed as reported in Section 2. Each column in Table 4 reports that year's percentage change in actual U.S. import prices (i.e., in the actual Laspeyres import price index); that year's percentage change in hypothetical U.S. import prices that would have occurred if the ITA had not happened (i.e., in the non-ITA Laspeyres import price index); the difference between these two changes; and the contribution to this difference made by the three Enduse categories that were fully covered by the ITA (see Table 1): computers, computer accessories, and semiconductors.

The key message of Table 4 is that in the absence of the ITA, U.S. import prices every year would have fallen less or risen more—by about one percentage point in the initial ITA years when many countries were cutting tariffs. In turn, most of this predicted difference comes from the central ITA categories. Thus, although Table 3 shows that various sources of mis-measurement matters for calculated U.S. terms of trade—and thus for calculated productivity growth, as Table 5 will show—Table 4 quantifies how important the ITA was in lowering actual U.S. import prices.[27]

The underestimation of terms of trade gains of 0.93 percent per year in 1996-2006 shown in Table 3 can be expected to result in significant overestimation of aggregate output and

[26] See note 23.

[27] In Table 4 we did not try simulate non-ITA terms of trade because we did not think it reasonable to hold constant export prices in the post-ITA years. Passage of the ITA may have reduced U.S. export prices in response to greater competition from now-lower-priced IT imports.

productivity growth. This question we investigate in Table 5. We first used 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 baseline indexes for these three higher level aggregates to ones calculated using Törnqvist indexes (with tariffs and variety growth included in the imports Törnqvist). The price indexes for value added also included tariffs in the import weights, as shown in equation (7). To aggregate the major components of the higher level aggregates (domestic final consumption, goods exports, services exports, non-petroleum goods imports, services imports and petroleum imports, plus government in the case of GDP and total value added) we experimented with both the Törnqvist formula and the Fisher formula. As expected, the Törnqvist and Fisher results were virtually identical.

The estimates of the growth rate of the price index for GDP are higher with Törnqvist export and import indexes than with the baseline indexes by amounts ranging from 0.07 to 0.20 percent per year in 1996-2006. The average effect is 0.12 percent per year (Table 5, section I). The effect on the price index for total value added (for which no official index exists) averages 0.13 percent per year during that period (Table 5, section II). That is, the corrected deflator for total value added grows by 0.13 more per year that the deflator based on the official import and export indexes. The slower growth of the corrected import indexes results in more rapid growth of the deflator for value added, and slower growth of real value added which translates into slower productivity growth of the virtually same magnitude.[28]

Because no reliable measure of government sector productivity exists, the most general measure of productivity that is available from BLS is for private business. The effect of correcting the export and import indexes on the price index for gross value added of private business ranges from 0.10 to 0.27 percent per year, with an average of 0.17 percent per over 1996-2006 (Table 5, 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.[29] The official quantity index for the output of private business (rebased to 1994=100) in 2006 is 154.0, compared with our corrected index of 151.4, with all of the 2.6 percentage point gap coming from the interval of 1996 to 2006 (Table 5, section IV). Unmeasured gains in terms of trade therefore add, on average, 0.16 percent per year to the official measure of private business productivity growth over the period 1996 through 2006.

To gauge the importance of this terms-of-trade mismeasurement, recall that reported growth in U.S. nonfarm labor productivity has accelerated from 1.37 percent during 1973-1995 to 2.69 percent during 1996-2010—i.e., by about 1.3 percent per year. Our results suggest that about one-eighth of this reported economy-wide acceleration in labor productivity should properly be accounted for as 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 20% – or one-fifth – of this reported economy-wide acceleration in TFP should properly be 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 5 are worth mentioning. First, we have included imported finished investment goods in our corrected import price indexes even though

[28] The quantity index for real value added also takes account of 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)). But this difference has only a minimal impact.

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. 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 3 and 5, 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 U.S. 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 changed the overall estimate of the unmeasured terms of trade gains in the next-to-last row of Table 5 by +0.05 percentage points in 1995 and by –0.15 percentage points in 1996 and 1997. On average over 1995-2006, the contribution of semiconductors to our estimate of unmeasured terms of trade gains is virtually zero, but in one year (2000) excluding semiconductors *raises* our estimate by 0.4 percentage points.

7. Conclusions

[29] The effect on real value added is not precisely the same in magnitude as the effect on the deflator because the calculation of real value added includes an adjustment for nominal tariff revenue.

At first glance, the roles of trade prices and trade barriers in aggregate productivity measurement might seem small. But as we have shown in this paper, 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 new methods for measuring these effects. We have then applied this framework to the important case of the post-1995 U.S. productivity acceleration.

Our main result is that approximately 20% of the apparent speed-up in U.S. productivity growth as officially reported was actually gains in the terms of trade and tariff reductions—especially for the IT products that have been the focus of much research on U.S. productivity. In generating this result, we analyzed three important sources of 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 average growth rates of our corrected price indexes for U.S. imports are 1.5% per year lower than growth rate of the index calculated using official methods, a key input to reaching our main result.

Although our focus in this paper was on the particular case of the post-1995 U.S. productivity acceleration, the issues we identified and methods we developed generalize along at least four important and related dimensions.

First, our analysis could be extended to address other U.S. price series that cover non-traded parts of the economy and thus help create aggregate productivity statistics. For example, deflators for domestic absorption are beyond the scope of the research in this paper but could be examined for possible biases due to expanded product variety.

Second, our analysis could be applied to better understand U.S. economic performance in earlier periods. From 1948 to 1973, for example, officially measured non-farm U.S. labor productivity grew at an annual average of 2.79% – a rapid rate that often leads this period to be a "golden generation" in U.S. economic history. But this was also a period of fast growth in U.S. trade with rapidly growing countries like Japan, and also of substantial U.S. trade liberalization thanks, e.g., to the Kennedy Round of the General Agreement on Tariffs and Trade. These broad facts suggest potential value in re-examining this period's productivity statistics.

Third, it would be worthwhile to examine multilateral tariff reductions in other sectors, to determine whether we find similar magnified reductions in import prices, as observed in section 2 under the ITA. In preliminary analysis, we have found a magnified impact of tariff reduction in chemicals (which was part of the control group in Section 2 and Table 2). It is noteworthy that that sector was indeed subject to a multilateral tariff reduction, under a 1995 Uruguay Round agreement called the Chemical Tariff Harmonization Agreement.

And fourth, our analysis could be extended to the growth experience of other countries. Countries such as China and India appear to have recently delivered productivity gains among the fastest the world has ever seen (the recent crisis notwithstanding). At the same time, many of these countries have rapidly integrated into the world economy with dramatic declines in trade barriers and surging trade flows. As with the post-World War II U.S. generation, so, too, the growth experiences of these other countries might look different by our analysis.

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 2006. 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. Nakamura and Steinsson (2009) analyze this item-level data. 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 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: Features of ITA Industries

Industry	% Imports covered by ITA	1997 Tariff (percent)	2000 Tariff (percent)	Drop in price due to ITA[b]
ITA = 1				
Computers (Enduse 21300)	100	1.4	0.0	16.0
Computer accessories (21301)	100	0.3	0.0	23.7
Semiconductors (21320)	100	0.0	0.0	2.1
0.1 < ITA < 1				
Blank tapes (16110)	92	1.5	0.0	n/a
Telecomm equipment (21400)	79	2.6	0.3	4.6
Lab Instruments (21600)	63	3.7	2.3	6.0
Records, tapes & disks (41220)	61	1.0	0.2	n/a
Electrical apparatus (20005)	48	2.3	1.1	1.5
Business machines (21500)	39	2.0	0.7	-1.0
Generators & access (20000)	38	1.6	1.5	-1.4
Measuring, testing, control instruments (21160)	30	1.8	0.9	20.3
Marine engines and parts (22220)[a]	23	1.6	0.3	n/a
Wood, glass, plastic (21140)	21	2.2	1.9	7.6
Photo, service industry (21190)	21	2.1	1.4	19.0
Metalworking machine tools (21120)	19	3.3	2.9	-4.2
Materials handling equip (21170)	16	0.4	0.1	n/a
Industrial supplies, other (16120)	13	2.1	1.7	21.3
Industrial machines, other (21180)	11	2.2	1.6	12.5

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.
b. The price drop due to the ITA is estimated as the cumulative difference (by end-2006) between the published BLS import price series and the predicted values of a pass-through regression (described in Section 2) holding tariff variables constant at their June 1997 levels for subsequent periods.

Table 2: Pass-Through Regressions
Dependent Variable – Import Price

	(1)	(2)	(3)	(4)	(5)	(6)
	Using nominal tariffs			Tariffs multiplied by [1/(1-θ)]		
	Share of products covered by ITA:			Share of products covered by ITA:		
	ITA=1	0<ITA<1	ITA=0	ITA=1	0<ITA<1	ITA=0
ITA1	-0.088**	-0.017**	-0.012**	-0.133**	-0.037**	-0.009**
	(0.020)	(0.005)	(0.003)	(0.024)	(0.006)	(0.003)
ITA2	-0.024	-0.004	-0.004	-0.070**	-0.003	-0.002
	(0.022)	(0.006)	(0.003)	(0.025)	(0.004)	(0.004)
ITA3	-0.077**	-0.034**	-0.016**	-0.088**	-0.034**	-0.019**
	(0.017)	(0.004)	(0.002)	(0.020)	(0.003)	(0.003)
U.S. Tariff	13.293**	2.434**	0.994**	1.534**	1.059**	0.721**
	(1.138)	(0.266)	(0.095)	(0.366)	(0.153)	(0.053)
Foreign Tariff	4.146**	0.320**	-0.007	0.721**	-0.008**	0.020**
	(0.238)	(0.040)	(0.017)	(0.059)	(0.017)	(0.006)
Peg Share	2.888**	-0.237	1.829**	1.332	1.185**	2.430**
	(0.863)	(0.421)	(0.163)	(0.992)	(0.300)	(0.172)
Exchange Rate	0.123*	0.033	0.247**	-0.248**	0.067**	0.284**
(6 lags)	(0.076)	(0.021)	(0.011)	(0.095)	(0.022)	(0.012)
Exchange Rate	-0.636**	0.010	-0.389**	-0.309	-0.271**	-0.506**
x Peg Share	(0.177)	(0.088)	(0.034)	(0.204)	(0.093)	(0.036)
Export Price	0.409**	1.136**	0.361**	0.415**	1.097**	0.335**
	(0.039)	(0.020)	(0.011)	(0.047)	(0.016)	(0.011)
Observations	459	2,760	3,821	435	2,556	3,871
R-squared	0.98	0.91	0.72	0.98	0.91	0.77

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

In columns (1) – (3), the U.S. tariff and a weighted average of foreign tariffs are used. In columns (3) – (6), these tariffs are multiplied by [1/(1-θ)], where θ is the share of imported intermediate inputs. Regressions are run for 5-digit Enduse industries, with monthly data from September 1993 – December 2006. Regressions with ITA=1 are run over those industries where 100% of the imports are covered by the ITA; regressions with 0 < ITA <1 are run over those industries where 1 – 99% of the import value covered by the ITA. The final regressions with ITA=0 are run over a control group of industries (Enduse 12, 2,3,4) that do not include any ITA commodities as imports. The regressions are estimated with OLS (including fixed effects for 5-digit Enduse industries), including 6 lags of the exchange rate.

Table 3: Effect of Lower-level Index Formula on Aggregate Fisher Price Indexes for Exports and Imports
(Differences in percent per year)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Ave. 96-06
I. Export Indexes (1994=100)													
Formula for lower-level aggregates													
Laspeyres	103.1	102.6	101.0	97.5	96.0	97.4	96.5	95.4	96.9	100.2	103.3	106.8	
Törnqvist	102.4	101.8	99.7	95.6	93.6	94.1	92.8	91.1	92.2	94.7	97.1	99.6	
Growth rate difference of Törnqvist from Laspeyres	-0.74	-0.13	-0.43	-0.65	-0.52	-0.92	-0.58	-0.55	-0.46	-0.65	-0.59	-0.82	-0.57
Contribution of IT goods to above difference	*-0.09*	*-0.18*	*-0.24*	*-0.4*	*-0.28*	*-0.63*	*-0.39*	*-0.18*	*-0.1*	*-0.21*	*-0.15*	*-0.24*	*-0.27*
II. Import Indexes (1994=100)													
Formula for lower-level aggregates													
Laspeyres	102.6	100.7	97.7	94.0	92.1	92.3	90.6	88.6	89.4	91.6	93.6	94.9	
Törnqvist	102.1	99.7	95.8	90.9	88.2	87.6	85.5	83.4	83.4	84.8	86.1	86.7	
Törnqvist, tariffs included in prices	101.8	99.3	95.3	90.3	87.5	86.9	84.8	82.5	82.5	83.9	85.1	85.7	
Törnqvist, adjusted for tariffs and varieties	101.7	98.7	94.1	88.4	85.4	84.5	81.8	79.2	79	79.6	80.5	79.8	
Growth rate difference from Laspeyres													
Törnqvist	-0.51	-0.47	-0.93	-1.31	-0.99	-0.91	-0.57	-0.23	-0.93	-0.74	-0.7	-0.7	-0.77
Törnqvist, tariffs included in prices	-0.80	-0.66	-0.98	-1.41	-1.13	-1.00	-0.55	-0.41	-0.96	-0.81	-0.71	-0.69	-0.85
Törnqvist, adjusted for tariffs and varieties	-0.94	-1.07	-1.65	-2.23	-1.37	-2.08	0.09	-1.59	-1.19	-1.71	-1.03	-2.18	-1.47
Contribution of IT goods to above difference	*-0.04*	*-0.34*	*-0.71*	*-0.76*	*-0.63*	*-0.49*	*-0.39*	*-0.10*	*-0.22*	*-0.22*	*-0.18*	*-0.17*	*-0.38*
III. Terms of Trade (1994=100)													
Formula for lower-level aggregates													
Laspeyres	100.4	101.9	103.4	103.8	104.2	105.5	106.5	107.7	108.4	109.4	110.4	112.6	
Törnqvist	100.2	102.0	104.0	105.2	106.1	107.4	108.5	109.3	110.6	111.7	112.8	114.9	
Törnqvist, tariffs included in prices	100.5	102.5	104.6	105.8	107.0	108.4	109.4	110.4	111.8	113.0	114.1	116.2	
Törnqvist adjusted for tariffs and varieties	100.6	103.1	105.9	108.1	109.6	111.4	113.4	115.1	116.8	119.1	120.7	124.8	
Difference from Laspeyres in annual growth rate													
Törnqvist	-0.23	0.35	0.53	0.7	0.48	0.00	0.00	-0.32	0.48	0.09	0.12	-0.10	0.21
Törnqvist, tariffs included in prices	0.06	0.55	0.59	0.81	0.63	0.10	-0.02	-0.14	0.51	0.16	0.13	-0.12	0.29
Törnqvist adjusted for tariffs and varieties	0.20	0.99	1.30	1.70	0.89	0.49	0.79	0.46	0.73	1.07	0.45	1.41	0.93
Contribution of IT goods to above difference	*-0.11*	*0.16*	*0.46*	*0.35*	*0.35*	*-0.15*	*0.00*	*-0.09*	*0.11*	*0.01*	*0.02*	*-0.07*	*0.11*

Notes:
All indexes are normalized to 100 in 1994. Lower-level aggregates 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 4: Comparing Changes in Actual U.S. Import Prices and Changes in Hypothetical U.S. Import Prices That Would Have Occurred without the ITA

	1998	1999	2000	2001	2002	2003	2004	2005	2006
Laspeyres Using Actual Import Prices	-3.84	-2.02	0.30	-1.86	-2.24	0.93	2.47	2.17	1.35
Hypothetical Laspeyres without ITA	-2.54	-1.12	0.79	-1.13	-1.66	1.19	2.58	2.51	1.63
Difference	1.30	0.90	0.48	0.74	0.58	0.26	0.12	0.34	0.27
Contribution of IT Goods to Difference	1.02	0.85	0.43	0.69	0.44	0.36	0.20	0.25	0.13

Notes:
Each column in Table 4 reports that year's percentage change in actual U.S. import prices (i.e., in the actual Laspeyres import price index, levels of which are reported in Table 3); that year's percentage change in hypothetical U.S. import prices that would have occurred if the ITA had not happened (i.e., in the non-ITA Laspeyres import price index); the difference between these two changes; and the contribution to this difference made by the three Enduse categories that were fully covered by the ITA (see Table 1): computers, computer accessories, and semiconductors. See Table 2 and related text discussion for calculation of hypothetical non-ITA import prices for Enduse categories covered under the ITA.

Table 5: 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

(Differences in percent per year)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Ave. 96-06
I. Price index for GDP													
baseline (official, rebased to 1994=100)	102.1	104	105.9	107.1	108.6	111.0	113.5	115.3	117.8	121.2	125.2	129.3	
adjusted for Törnqvist formula	102.1	104.1	106.0	107.2	108.9	111.3	113.8	115.6	118.2	121.6	125.7	129.8	
adjusted for Törnqvist formula & tariffs /a/	102.1	104.1	106.0	107.3	109	111.4	113.9	115.8	118.3	121.7	125.9	130.0	
adjusted for Törnqvist formula, tariffs & variety	102.1	104.2	106.1	107.5	109.2	111.7	114.3	116.2	118.9	122.4	126.6	131.0	
Growth rate difference from baseline for above index	*0.03*	*0.10*	*0.13*	*0.18*	*0.11*	*0.08*	*0.11*	*0.07*	*0.09*	*0.14*	*0.08*	*0.20*	*0.12*
II. Price index for Total Value Added													
Adjusted for Törnqvist formula	102.1	104.1	106.0	107.3	109.0	111.4	113.9	115.7	118.3	121.7	125.8	130.0	
Adjusted for Törnqvist formula & tariffs	102.1	104.1	106.1	107.4	109	111.5	114.0	115.9	118.4	121.9	126.0	130.1	
Adjusted for Törnqvist formula, tariffs & variety	102.1	104.2	106.2	107.6	109.3	111.8	114.4	116.4	119.0	122.5	126.7	131.1	
Growth rate difference from baseline for above index	*0.03*	*0.12*	*0.15*	*0.20*	*0.12*	*0.09*	*0.12*	*0.08*	*0.10*	*0.15*	*0.08*	*0.21*	*0.13*
III. Price Index for Private Business Value Added													
baseline (official, rebased to 1994=100)	101.8	103.4	105	105.8	106.6	108.6	110.5	111.3	112.9	115.8	119.6	123.1	
adjusted for Törnqvist formula	101.8	103.5	105.2	106.1	107.0	109.0	111.0	111.8	113.5	116.5	120.4	124.0	
adjusted for Törnqvist formula & tariffs /a/	101.8	103.5	105.3	106.1	107.1	109.1	111.1	112	113.7	116.7	120.6	124.1	
adjusted for Törnqvist formula, tariffs& variety	101.8	103.6	105.5	106.4	107.4	109.5	111.6	112.6	114.4	117.5	121.5	125.4	
Growth rate difference from baseline for above index	*0.04*	*0.15*	*0.20*	*0.26*	*0.15*	*0.12*	*0.15*	*0.10*	*0.13*	*0.19*	*0.10*	*0.27*	*0.17*
IV. Quantity Index for Private Business Value Added													
baseline (official, rebased to 1994=100)	102.8	107.5	113.1	118.7	125.3	131	132	134.6	138.8	144.6	149.4	154.0	
adjusted for Törnqvist formula	102.8	107.5	112.9	118.5	125.0	130.6	131.6	134.2	138.2	143.9	148.7	153.1	
adjusted for Törnqvist formula & tariffs /a/	102.8	107.4	112.9	118.4	124.9	130.4	131.4	134.0	138.0	143.7	148.4	152.9	
adjusted for Törnqvist formula, tariffs& variety	102.8	107.3	112.7	118.0	124.5	129.9	130.8	133.3	137.2	142.7	147.3	151.4	
Growth rate difference from baseline for above index	*-0.02*	*-0.12*	*-0.20*	*-0.25*	*-0.13*	*-0.12*	*-0.13*	*-0.07*	*-0.13*	*-0.19*	*-0.10*	*-0.28*	*-0.16*

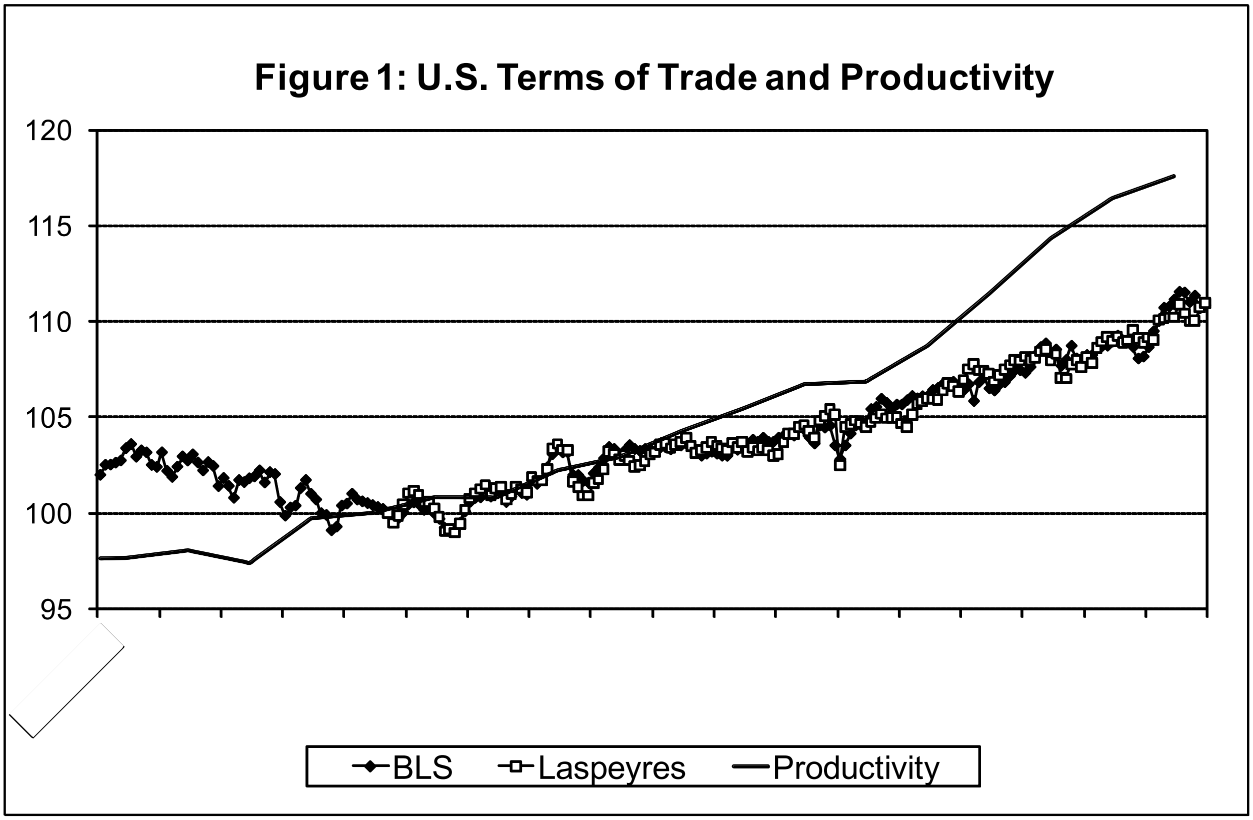


Figure 1: U.S. Terms of Trade and Productivity
120
115
110
105
100
95
BLS
Laspeyres
Productivity

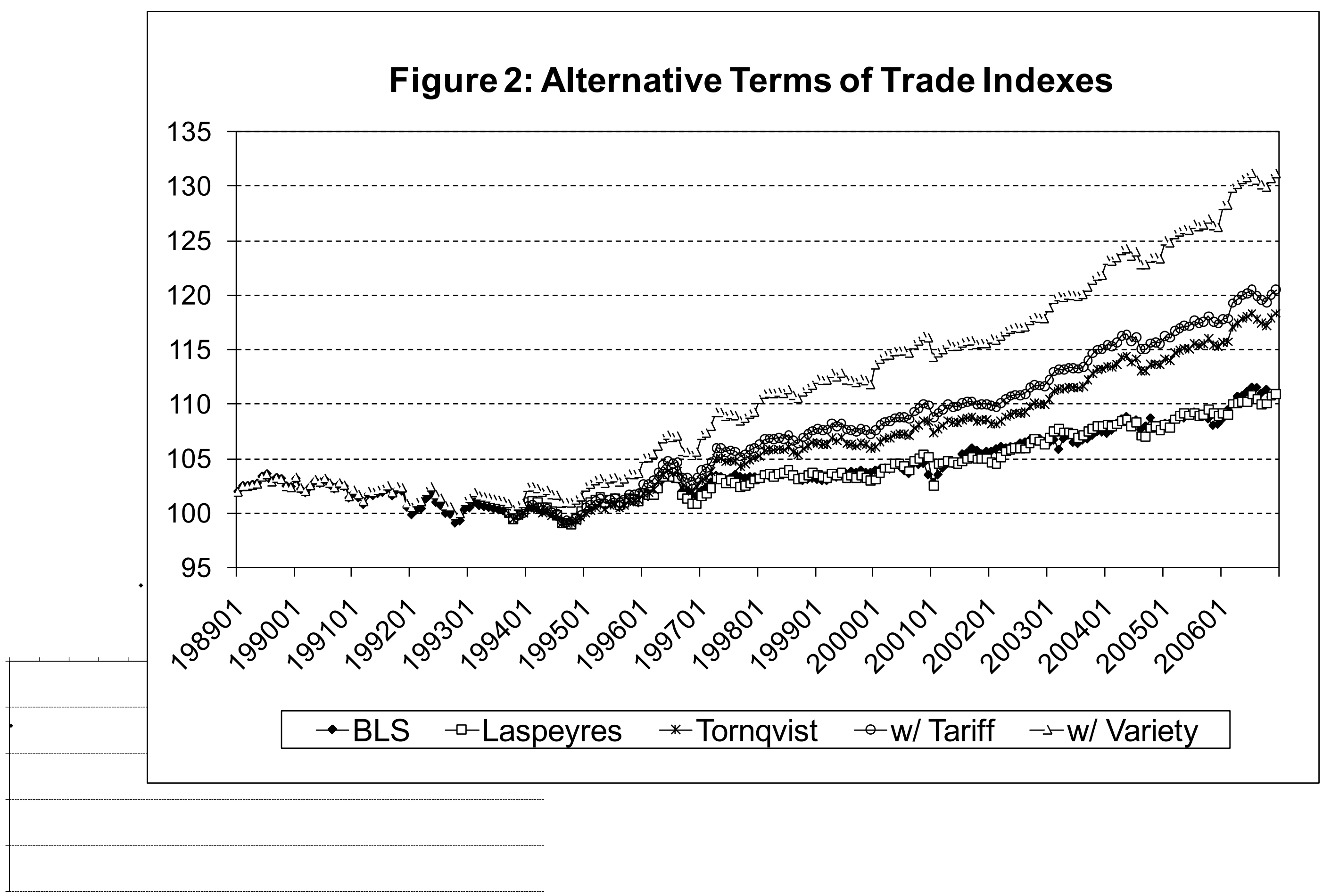


Figure 2: Alternative Terms of Trade Indexes
135
130
125
120
115
110
105
100
95
198901
199001
199101
199201
199301
199401
199501
199601
199701
199801
199901
200001
200101
200201
200301
200401
200501
200601
BLS
Laspeyres
Tornqvist
w/ Tariff
w/ Variety

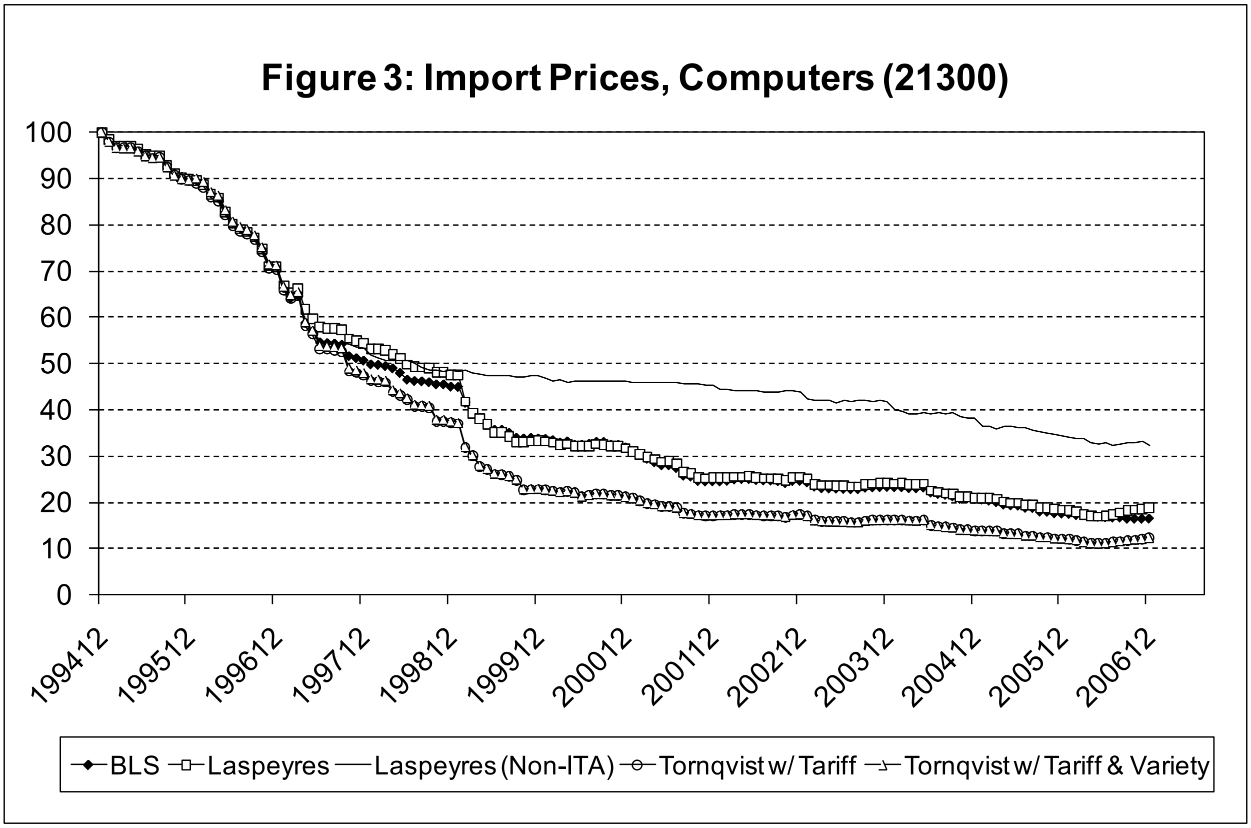


Figure 3: Import Prices, Computers (21300)
100
90
80
70
60
50
40
30
20
10
0
199412
199512
199612
199712
199812
199912
200012
200112
200212
200312
200412
200512
200612
BLS
Laspeyres
Laspeyres (Non-ITA)
Tornqvist w/ Tariff
Tornqvist w/ Tariff & Variety

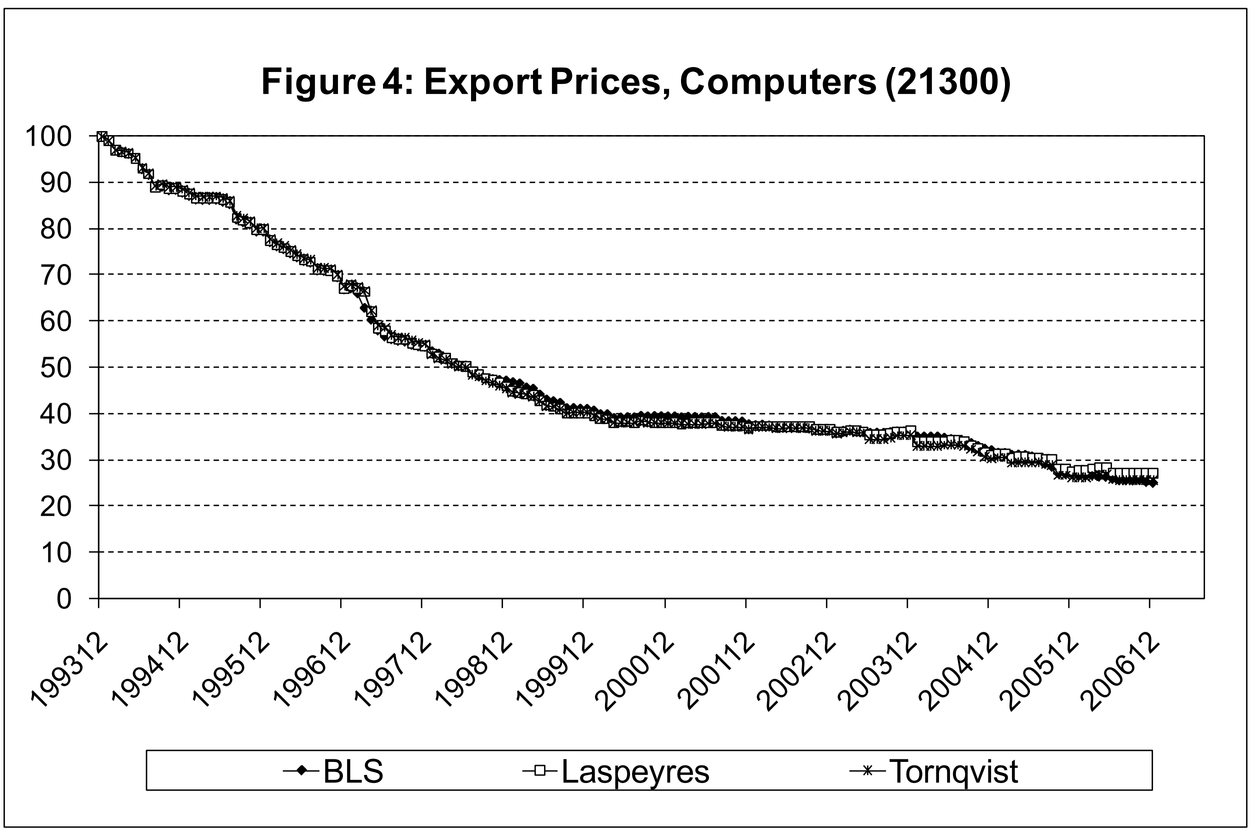


Figure 4: Export Prices, Computers (21300)
100
90
80
70
60
50
40
30
20
10
0
199312
199412
199512
199612
199712
199812
199912
200012
200112
200212
200312
200412
200512
200612
BLS
Laspeyres
Tornqvist

Figure 5: Import Prices, Computer Accessories (21301)

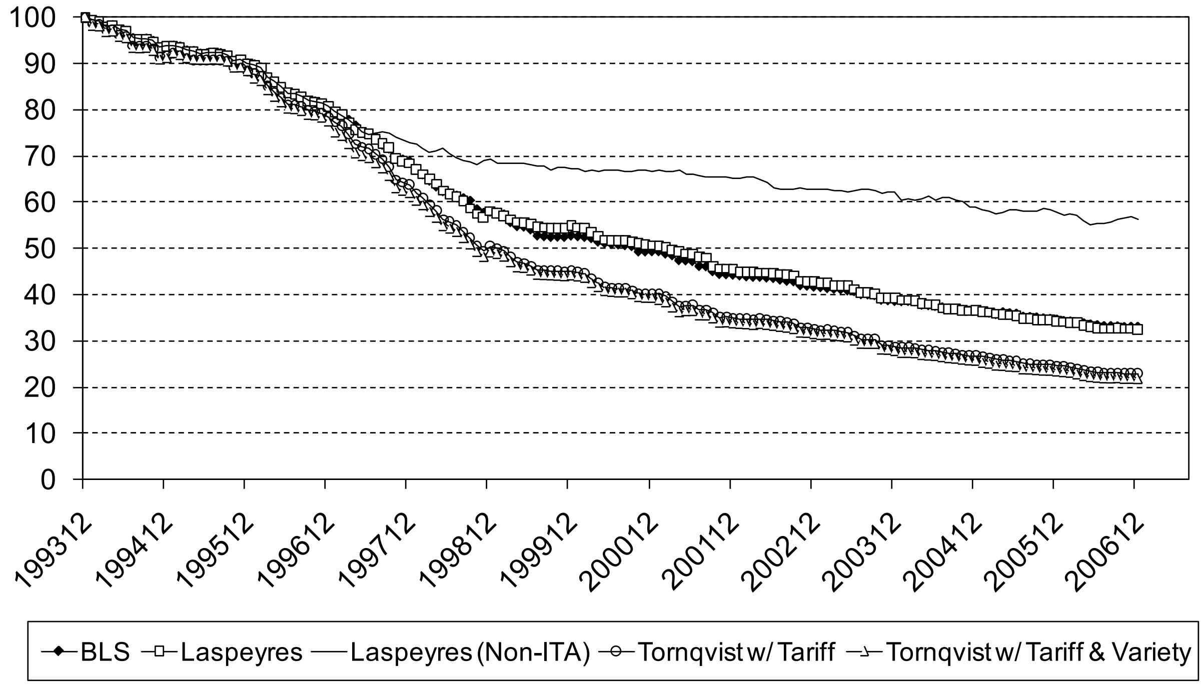
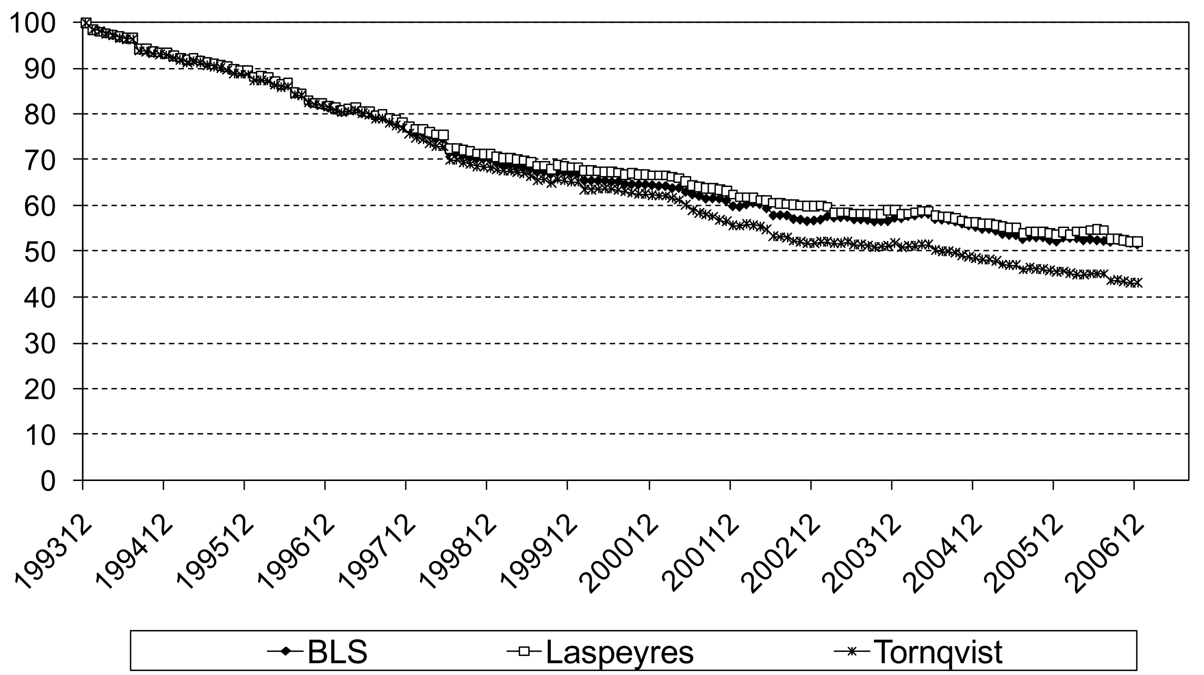


Figure 6: Export Prices, Computer Accessories (21301)



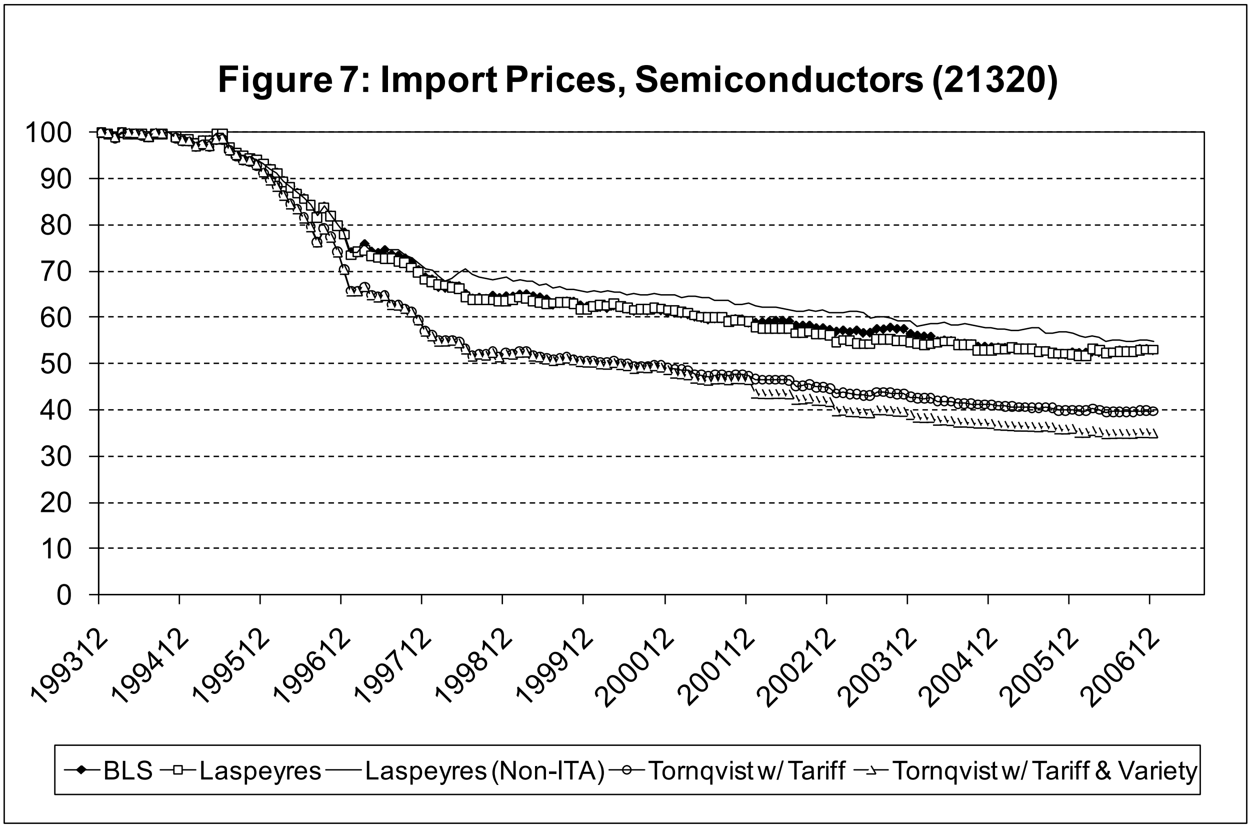


Figure 7: Import Prices, Semiconductors (21320)
100
90
80
70
60
50
40
30
20
10
0
199312
199412
199512
199612
199712
199812
199912
200012
200112
200212
200312
200412
200512
200612
BLS
Laspeyres
Laspeyres (Non-ITA)
Tornqvist w/ Tariff
Tornqvist w/ Tariff & Variety

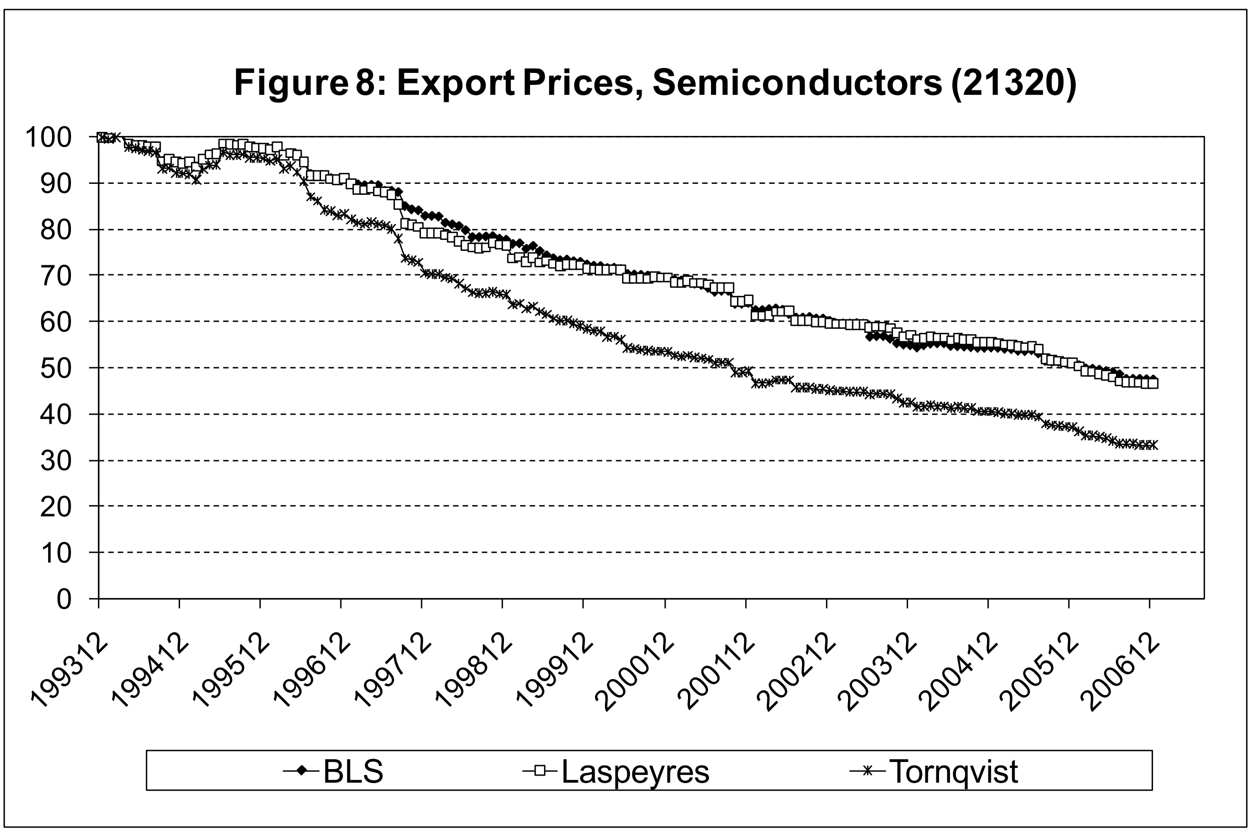


Figure 8: Export Prices, Semiconductors (21320)
100
90
80
70
60
50
40
30
20
10
0
199312
199412
199512
199612
199712
199812
199912
200012
200112
200212
200312
200412
200512
200612
BLS
Laspeyres
Tornqvist

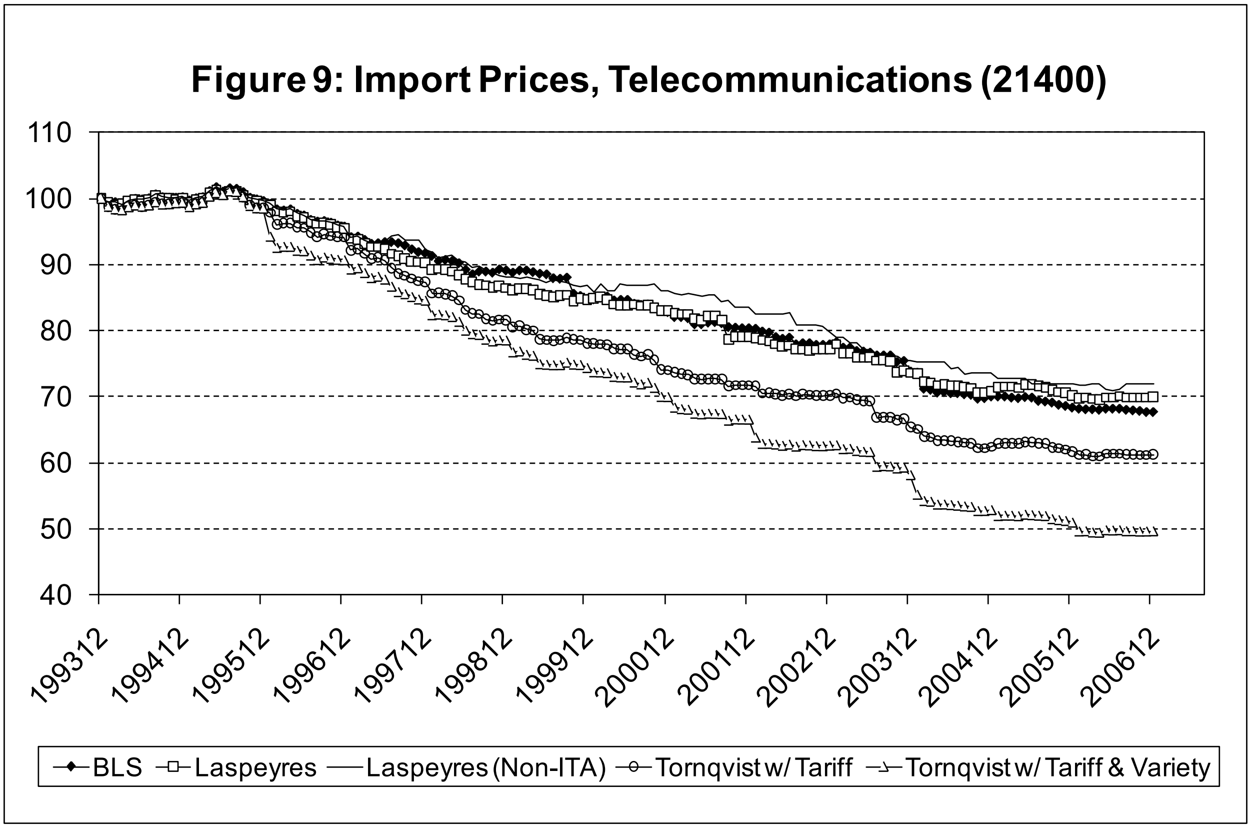


Figure 9: Import Prices, Telecommunications (21400)
110
100
90
80
70
60
50
40
199312
199412
199512
199612
199712
199812
199912
200012
200112
200212
200312
200412
200512
200612
BLS
Laspeyres
Laspeyres (Non-ITA)
Tornqvist w/ Tariff
Tornqvist w/ Tariff & Variety

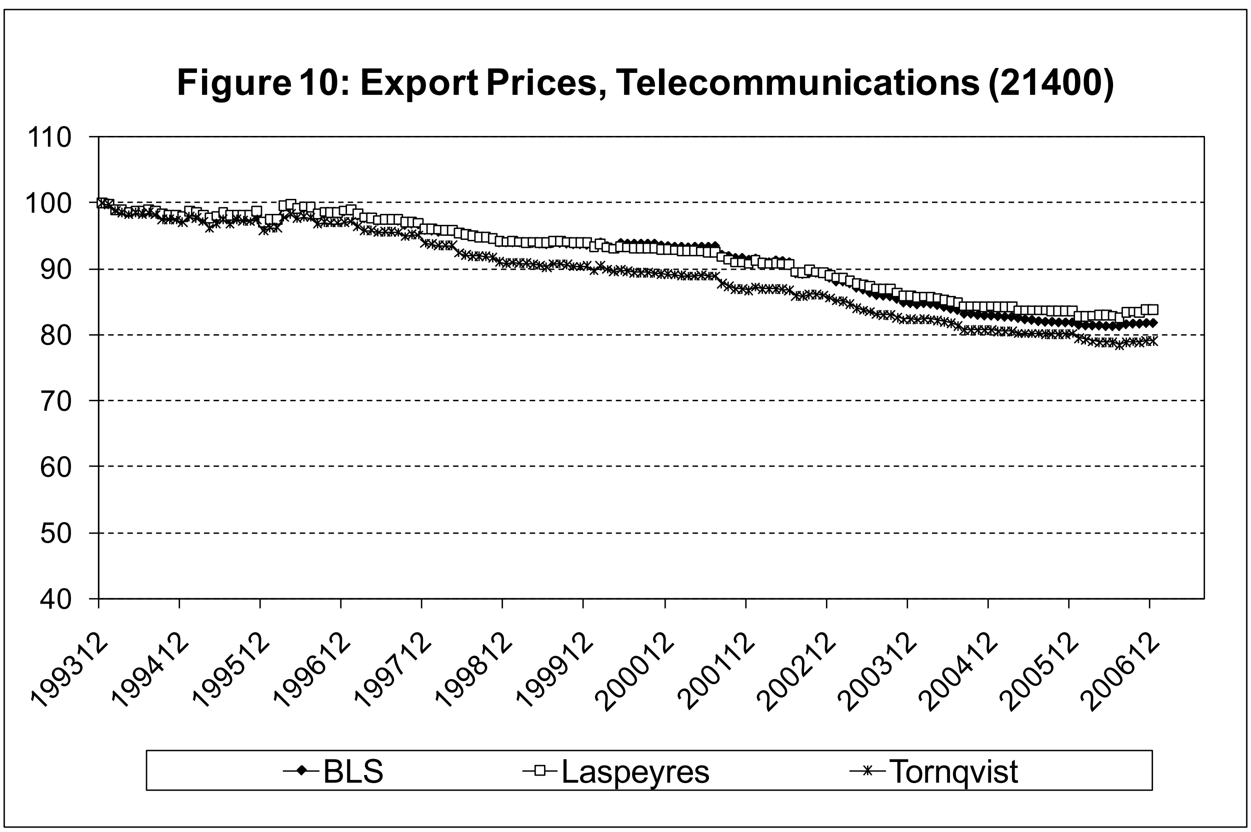


Figure 10: Export Prices, Telecommunications (21400)
110
100
90
80
70
60
50
40
199312
199412
199512
199612
199712
199812
199912
200012
200112
200212
200312
200412
200512
200612
BLS
Laspeyres
Tornqvist