International Transport costs: New Findings from modeling additive costs

Answer to Referee 1

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We would like to thank you for your insightful comments. They led us to introduce some significant changes to the paper that we hope address your concerns. We first give you a overview of the revision (Section 1) before answering in detail each of your comments (Section 2). Number of sections, pages and equations mentioned in the text refer to the revised version. When necessary, we refer to number of sections, pages and equations from the submitted version. In this case, they are written between brackets.

1 Main changes

The structure of the paper has been modified after taking into account the referees' comments.

- In the submitted version, [Section 2] was devoted to the estimation of international transport costs; specifically, their break-down in two components, additive and ad-valorem. In [Section 3], we investigated the role of additive costs in the decomposition of transport costs time trends, between structural changes and composition effects. [Section 4] was devoted to the robustness analysis relative to the results from both previous sections.

- In the revised version, we have strengthened the robustness checks regarding the estimation of international transport costs (robustness checks to the level of aggregation and to endogeneity have been added). Accordingly, the previously-called [Section 2] has been split in two Sections: Section 2, where we present the data and the estimation strategy; and Section 3, where we present the results. Section 3 now includes the robustness checks as a final sub-section. For the sake of saving space,

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the robustness analysis related to composition effects has been sent to the Appendix (Section C.3).

- Both referees asked us to devote more developments to the implications of additive costs (the "Big Picture"). We agree that this was not emphasized enough in the submitted version, and we thank the referees for their suggestions on that issue. The revised version answers this concern in two points.

    1. We maintain the analysis of the transport costs time trends (previously [Section 3], now Section 4); but we improved this section's readability by leaving the technical aspects in the Appendix (Section C). As such, we hope that the main message of this Section is easier to understand.
    2. More importantly, we now emphasize the "Big Picture" welfare implications of additive costs on theoretical grounds. Through the lens of the Mélitz's (2003) model amended to integrate additive costs, we analyze the welfare gains deriving from the reduction in international transport costs estimated in Section 3 over 1974-2019. In this regard, we shed light on the welfare variations induced by the "hyper-globalization" period. This also allows us to quantify the extra welfare gains attributable to reduction of additive trade costs. This analysis is performed in Section 5.

- To keep the paper (both the main text and its various appendices) within a reasonable number of pages, and stay fully transparent about our results, we have added numerous detailed tables to the Online Appendix.

We now answer in detail each of your comments given in italics.

2 Detailed answers

2.1 Critique 1: Empirical Strategy

Using the notation of the authors, they are interested in identifying the share of the specific cost in the total transport cost. Namely,

$$\frac{\frac{t_{is(k)}}{\tilde{p}_{ik}}}{\tau_{is(k)} - 1 + \frac{t_{is(k)}}{\tilde{p}_{is(k)}}}$$

$$\text{or,} \qquad \frac{t_{is(k)}}{(\tau_{is(k)} - 1)\tilde{p}_{is(k)} + t_{is(k)}}$$

The way they approach the problem is that they assume that (a) $\tau_{ik} = \tau_i \tau_k$, (b) $t_{ik} = t_i + t_k$, and (c) t_k and τ_k are uniform across products within industry s. After imposing these assumptions, they estimate the following specification

$$\ln\left(\frac{p_{ik}}{\widetilde{p}_{ik}} - 1\right) = \ln\left(\tau_i \times \tau_{s(k)} - 1 + \frac{t_i + t_{s(k)}}{\widetilde{p}_{ik}}\right) + \epsilon_{ik} \tag{1}$$

in which τ_i, $\tau_{s(k)}$, t_i, and $t_{s(k)}$ are identified as fixed effects coefficients. In my opinion this choice of strategy is quite sub-optimal, as (i) it relies on the strong assumptions highlighted above, (ii) it is computationally expensive as noted by the authors on multiple occasions, and (iii) it is subject to an endogeneity problem, which the authors disregard with one sentence, but which is rather detrimental in my opinion.

These three points indeed deserve careful consideration. We provide separate answers to each of them below.

2.1.1 Concern (i): About the assumption of separability

Our main empirical equation and its underlying assumptions regarding the separability of transport costs between their country- and product-level components draw on the one proposed by Irarrazabal et al. (2015) to estimate the share of additive costs in a firm-level context. It relies on a simple theoretical framework with minimal assumptions, and is compatible with most approaches within the so-called category of "New Trade Theories".

Further, we provide a robustness check for this separability assumption that $\tau_{ik} = \tau_i \tau_k$ and $t_{ik} = t_i + t_k$ in Section 3.3.1 of the paper (see Table 2 and Figure 3 on pp. 14-15). We check the robustness of our results by re-running the estimation without the separability assumption. This comes at the cost of a substantial increase in the number of fixed in the regression. In 2019, for example, there are 14,016 country$\times$sector pairs. Without the separability assumption, one must estimate 28,032 fixed effects (number of country pairs $\times 2$ for the two additive and multiplicative costs fixed effects) rather than "only" 836 $((188 + 230) \times 2)$. This is computationally impossible. For this reason, we have decided to run the robustness check on a reduced sample. For each year, we identify *(i)* the largest exporters that form together at least 80% of annual trade and *(ii)* the largest traded sectors that form together at least 80% of annual trade. We keep in the sample all trade observations that belong to both sets of exporters and sectors.

This sample is smaller in terms of observations (2,125 for Air, 5,260 for Vessel on average over the period 1974-2019 (see Table 2 in the paper), vs more than 30,000 on the complete sample (see Table 1 in the paper). It yet remains quite large in terms of trade coverage (mean of 68%).[1] As we conclude at the end of Section 3.3.1, the trend pattern of the share of additive costs are very similar whether estimated under the separability assumption or not.

2.1.2 Concern (ii): On the use of non-linear least squares (NLS)

As noted by the referee (and in the paper), it is true that relying on the non-linear least squares method is highly demanding computationally when the number of fixed effects is high. This constraint notably drove us to impose the separability assumption and retain $s = 3$ as the relevant sectoral degree of aggregation.

[1] In the restricted sample at the 3-digit level, we have 25 sectors from 14 countries for Air transport, vs 212 sectors from 190 countries in the baseline sample; and 54 sectors from 20 countries for Vessel, vs 667 sectors from 192 countries in the baseline sample). The vast majority of US imports comes from a selected range of countries, in a selected range of sectors.

The referee writes: *A more natural approach is what the authors, at some point, refer to as the Hummels' Methodology. That is, one can alternatively estimate the share of the additive component as:*

$$\frac{t_{ik}}{(\tau_{ik}-1)\tilde{p}_{ik}+t_{ik}}=\beta_{ik}$$

where β_{ik} is the elasticity of transport costs w.r.t. unit price. Given the authors' objective and the data they are using, β can be separately estimated for each industry-country pair using the following regression:

$$\ln f_{ikd} = \beta_{is(k)} \ln \tilde{p}_{ikd} + \text{Controls}_{ikd} + \epsilon_{ikd} \tag{2}$$

where d denotes the US district of entry and k denotes an HS10 product (f_{ikd} being the transport costs). *The identification of β_{ik}, in this case, would rely on the across HS10 product and district-of-entry variation in f_{ik} and p_{ik}. Estimating the above equation would obviously require that the authors do not aggregate up the raw Census data across all districts and all 10-digit products pertaining to the same 5-digit category. [...] The first advantage of this so-called Hummels' approach is that the above regression can be estimated separately for various country-industry pairs, without imposing Assumptions (a) and (b) outlined above.*

Our answer: First of all, we thank the referee for suggesting to improve the comparison between our method and Hummels' one. We took this remark into account by adding a new subsection in the revised version (Section 2.2, paragraph "Estimation strategy"). As we now show in this subsection, the elasticity of transport costs to unit prices $\beta_{is(k)}$ (in absolute value) also corresponds to the share of additive costs in total transport costs. The share of additive costs can hence be uncovered by regressing transport costs on unit fas prices, along the lines you suggest.

Now coming to the technical side, we thank the referee for his/her relevant suggestion of an alternative estimation method. This drove us to question our own empirical specification deeper. In the end, we decided to maintain our empirical strategy in the revised version, because its advantages seem to overweight its costs, and the alternative that the referee suggests does not go without a few important limitations. We develop each line of argument in our answer. Yet, because the referee's estimation method is also an interesting alternative, we have added a new section in the Online Appendix devoted to the latter (Section D.3).

Estimating the share of additive costs: Highlighting some requirements Our estimated equation relies on non-linear estimation methods. However, even with another formulation, such as the one suggested by the referee in Equation (2), we would still be constrained to resort to non-linear estimators. This is due to the necessity of imposing an *ex-ante* restrictions on parameters, i.e. $\tau \geq 1$ and $t \geq 0$, or $0 \leq \beta \leq 1$. Should we relax these restrictions, standard linear, least squares estimates often deliver negative, meaningless estimates. In this respect, implementing the referee's method (see below) does not dispose of the requirement of resorting on non-linear estimates (and the computational, time-consuming burden it induces – though the referee's method is indeed less computational intensive). Imposing this parameters constraint was not made clear enough in the initial version, and we did our best to make this very important justification clearer in the revised version. We hope that the new explanation provided in Section 2.2 (specifically pp. 7-8) now fulfills this requirement.

Exploring Referee's alternative functional form The estimation strategy suggested by the referee starts from Equation (3) linking transport costs and unit prices as assumed in Hummels (2007), yielding Equation (2) as estimation equation. By year and transport mode, this implies running the estimation for each country of origin i and each $s(k)$ = 3-digit sector, exploiting the variability between sub-sectors at the 10-digit level (k) and between ports of entry in the US (d). Despite its interest, the referee's method has some drawbacks, that in our view outweighs those of our method (in particular associated with *Assumptions (a)* $\tau_{ik} = \tau_i \tau_k$*, and (b)* $t_{ik} = t_i + t_k$). Our answer can be articulated in two steps. First, we debate the advantages that the referee's estimation method would bring in comparison with ours. Second, we emphasize the drawbacks induced by this method.

a) The advantages of the referee's method are not as specific to this method as suggested

- *The first advantage of this so-called Hummels' Approach is that the above regression can be estimated separately for various country-industry pairs, without imposing Assumptions (a)* $\tau_{ik} = \tau_i \tau_k$*, and (b)* $t_{ik} = t_i + t_k$.

  Our answer: As already discussed in this answer, the separability assumption does not seem to be a strong assumption. This is based on the conclusion drawn from the robustness check on a reduced sample. As we conclude at the end of Section 3.3.1, whatever the transport mode and for both types of transport costs, the trend patterns of international transport costs are very similar whether estimated under the separability assumption or not.

- *The second advantage is that there is a handful of previously-proposed instruments (e.g., HS-10 product-specific tariff rates or lagged prices), which the authors can use to overcome the endogeneity problem.*

  Our answer: We thank the referee for this valuable suggestion. It is worth noticing that we can also handle the instrumentation of fas prices at the HS-10 level with our method - which we do in the revised version (see sections 3.3.2 and B.3 in the paper).

- *The third advantage is that, by adopting this approach, the comparison between the paper [...] and those in Hummels (2007) would become more transparent.*

  Our answer: We agree with the referee that the comparison with the literature

(Hummels, 2007, in particular) was not straightforward for the reader in the initially submitted version. We did our best to make the comparison clearer in the revised version, in a way consistent with our estimation method. In contrast to the submitted version, the paper now starts from the relation linking transport costs to the unit price specified in Hummels (2007):

$$f_{ikt} = X_{is(k)t}\widetilde{p}_{ikt}^{-\beta_{ikt}} \tag{3}$$

with $f_{ikt} = \frac{p_{ikt}}{\widetilde{p}_{ikt}} - 1$ the transport costs measure, p_{ikt} ($\widetilde{p}_{ikt}$) the cif (fas) price and β_{ikt} the price-elasticity of transport costs, with i the origin country, k the product and t for time. As we now show in the paper (Section 2.2, pp. 6-7), β_{ikt} also corresponds to the share of additive costs in total transport costs:[2]

$$\beta_{ikt} = \frac{\frac{t_{is(k)}}{\widetilde{p}_{ikt}}}{\tau_{is(k)t} - 1 + \frac{t_{is(k)t}}{\widetilde{p}_{ikt}}} \tag{4}$$

Equation (3) lies at the root of Hummels' (2007) method. In contrast to our method though, Hummels (2007) estimates Equation (3) on a panel basis and at the sectoral $s(k)$ basis, assuming a mode-specific β invariant over time/sector/origin country. Rather than Equation (3), this amounts starting from the functional form: $f_{ikt} = X_{is(k)t}\widetilde{p}_{ikt}^{-\beta}$.

Two alternative strategies are possible. Let us start with our interpretation of the referee's method. It starts from the functional form linking transport costs and the fas price as specified in the Equation (3). Taken in log (on a mode/yearly basis), it is written as:

$$\ln f_{ikd} = \beta_{is(k)} \ln \widetilde{p}_{ikd} + \text{Controls}_{ikd} + \varepsilon_{ikd}$$

with d the district of entry. From this, one can then recover the levels of additive / multiplicative transports costs. Denoting $\widehat{\beta}_{is(k)}$ the estimated β for a given sector-country $i, s(k)$, one can indeed solve the following two-equation system:

$$\begin{aligned} p_{ik} &= \tau_{is(k)}\widetilde{p}_{ik} + t_{is(k)} && (5) \\ \frac{t_{is(k)}}{(\tau_{is(k)} - 1)\widetilde{p}_{ik} + t_{is(k)}} &= \widehat{\beta}_{is(k)} && (6) \end{aligned}$$

with p_{ik} and $\widetilde{p}_{ik}$ are respectively the cif and fas prices observed in our dataset (conditional on a given year-transport mode). With two equations and two endogenous variables, the system can be solved.

[2]For sake of expositional purpose, the reasoning is made without any i, k, t specification in the revised paper. We directly report them here to ease the comparison with the referee's method afterwards.

Alternatively, our method rather starts from the definition of transport costs as:

$$\ln f_{ik} = \ln\left(\tau_{is(k)} - 1 + \frac{t_{is(k)}}{\widetilde{p}_{ik}}\right) + \varepsilon_{ik}$$

from which we deduce the additive/multiplicative costs $\widehat{t}_{is(k)}$, $\widehat{\tau}_{is(k)}$ (on a mode/yearly basis). One can then deduce the share of additive costs in total transport costs β_{ik} through Equation (4), again on a mode/yearly basis.

In this respect, the referee's method and ours are equivalent, in that they both allow to uncover the share of additive costs in total transport costs β, as well as the value of each trade costs component (t, τ), that vary over time, country, sector and transport mode. In other words, our method is consistent with Hummels' methodology - provided that it is adequately reported as such. We agree that this was not the case in the submitted version and we hope that this revised version is now convincing enough on that side.

In comparison with Hummels (2007), one supplementary advantage of our method is that we estimate a β that varies over time, origin country and sector. Section 4 ([Section 3] in the initially submitted version) explores the importance of allowing for such a variability in accounting for the sources of the transport costs time trend. We agree that this was not sufficiently transparent in the submitted version. We hope that the revised version now fulfills the referee's expectations on this point.

As previously noted, running this estimation limits the time coverage as information is available at the HS-10 level and by ports of entry only since 1989 (though we could not obtain the whole data because of Covid). We have thus run referee's method over the years 2005-2013, at the $s = 3, k = 10$ sectoral/product levels, and reported the results in the Online Appendix, Section D.3, Table D.1 and Figure D.3.[3] For the referee's convenience, we also report the results of Table D.1 here (Table 1).

Regarding the share of additive costs β, the comparison between the two methods delivers opposite conclusions depending on the transport mode. While the estimated β is lower for vessel transport with the alternative method (also displaying a larger decrease over the period), the opposite holds for air transport. In any case, the share of additive costs remains substantial, around 40% on average across transport modes over the period. In this respect, it confirms the main message of our paper shedding light on the importance of the additive component in international transport costs.

Yet, the suggested method does not go without a few important limitations, that we now develop.

b) The referee's method is not without drawbacks

Concern 1 The suggested estimation strategy implies having much less data to cover.

[3] Note that we are aware of the referee's suggestion to run his/her estimation strategy considering sectoral aggregation at the 5-digit level (with $k = 10$). We yet keep considering sectors at the 3-digit aggregation level, in view of being able to compare the referee's method versus ours.

Table 1: Comparison 2005-2013

Transport mode	Air		Vessel	
Estimation method	Alternative	Baseline	Alternative	Baseline
Coverage				
Nb sectors	177	217	203	227
Nb partners	112	210	123	204
Nb pairs	3,872	12,158	3,743	12,440
Annual covered value (Bn USD)	262	293	824	906
Share of additive costs β				
Mean	0.39	0.25	0.45	0.50
Median	0.39	0.22	0.41	0.48
Std. dev.	0.15	0.19	0.29	0.28
Time trend coefficient	-0.012	-0.020	-0.012	-0.031

Notes: Time trend coefficient is the annual growth rate.

As noted above, the suggested method implies that the estimation is run at the sector-country level (on top of being mode-year specific), exploiting the variability within each origin country-3digit sector pair across 10-digit sub-sectors and ports of entry. Yet, it appears that for many couples (country, 3-digit sector), there is too few variability across sub-sectors or ports of entry given the number of fixed effects included in the regression to estimate the equation. This can be seen comparing the number of observations by year/ transport mode with our method / with the referee's method reported in the online appendix, Table D.1 of Section D.3 (and here in Table 1). Put differently, this methodology discards country-sector pairs that export a limited range of goods to the US and/or which arrive in the USA through the same ports of entry. This may induce a selection bias in the sample covered for estimation. As reported in Table 1, the number of pairs covered is much lower (especially in the list of countries covered). This concern is mitigated by noticing that the covered value of trade flows is only slightly lower. If it reduces the sample of sectors and origin countries covered, this method preserves the majority of trade flows in value.

The most important limitation rather comes from the coverage period. Information about the port of entry is only available since 1989, which is already smaller than our full sample starting in 1974. On top of that, because of the Covid situation, the US Bureau of Census was only able to send us the data relative to the years 1997-1999 and 2001-2019. Implementing the referee's method would hence necessarily reduce the time coverage of our analysis by more than 20 years (skipping the 1974-1996 years in particular). In our view, the historical coverage is interesting per se, as it provides useful insights about how transport costs have evolved over a period including years when globalization was specifically intense, and the induced long-run welfare variations. Eliminating this dimension of the paper would be detrimental to its contribution.

Concern 2 The suggested method features less accuracy in the estimation of the β.

If we take the value of the β by itself, there is no clear criterion to discriminate between the value estimated with our method and the one obtained with the suggested method (when, of course, run on the same sample). Further, Table 1 does not show any clear sign of a potential upwards or downwards bias that would be attached to our method. Things are more clear-cut in terms of accuracy of the estimation. Specifically, our method yields a more accurate estimation of the β than the referee's method. We reach this conclusion by implementing the following reasoning (for each year and transport mode):

- With the referee's method (referred to as the "direct method" in the Online Appendix), we estimate one value for the share of additive component β at the i, s level denoted $\hat{\beta}^{dir}_{is(k)}$ associated with a standard deviation SD_{is}, by year and transport mode. From this, we can compute the size of the 5-95% confidence interval $CI^{dir}_{is} = \hat{\beta}^{max,dir}_{is} - \hat{\beta}^{min,dir}_{is}$ where:

$$\hat{\beta}^{min,dir}_{is} = \hat{\beta}^{dir}_{is(k)} - 1.96 SD_{is}, \quad \hat{\beta}^{max,dir}_{is} = \hat{\beta}^{dir}_{is(k)} + 1.96 SD_{is}$$

  where the ^{dir} subscript identifies the direct method.

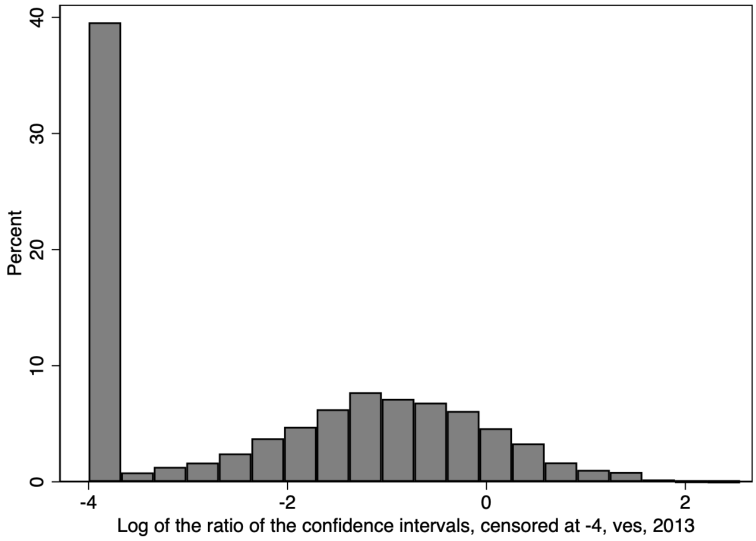
- Our method provides estimates of the underlying trade costs components ($\widehat{\tau}_i$, $\widehat{\tau}_s$, $\widehat{t}_i$, $\widehat{t}_s$) with an associated matrix of variance-covariance, from which we can rebuild β_{is} (on a year-transport mode basis). As such, it does not yield an estimate of β_{is} and an associated standard deviation, so that we cannot directly compare the precision of the estimation. We hence compute the accuracy of the β estimation through a bootstrap method. Specifically, on a yearly/mode basis we draw a distribution of transport costs components and associated β_{is} (10,000 random draws) from which we can compute the mean, the median and the 5-95 confidence interval for each couple i, s.[4] Writing β^{95}_{is} and β^{05}_{is} the associated thresholds, we then obtain the size of the confidence interval $CI_{is} = \beta^{95}_{is} - \beta^{05}_{is}$.

- We can then evaluate the accuracy of each estimation method by comparing the size of the confidence intervals of the β, for each couple i, s (by year and transport mode). We summarize this comparison in Figure 1, which reports the distribution of the ratio of confidence intervals, taken in log.

  XXXX AJouter le complement sur Air et stop XXX In most cases, the log of the ratio is negative, implying a smaller interval confidence of the baseline β estimation. Our method thus yields more accurate estimations of the share of additive components, whatever the transport mode considered. We have checked that a similar conclusion applies on other years (they are not reported here for sake of brevity but they are available upon request).

[4] Notice that this should be made on the same sample as the one obtained with the referee's method, since the goal is to compare the accuracy of the β_{is} estimate - implying to have the same sample of countries-sectors at first.

Figure 1: Accuracy of the estimation of the β: Comparison



Note: Ratio of the confidence intervals = $ln(CI_{is}/CI_{is}^{ref})$

One explanation of the limited accuracy of the direct method might be the following. Given that the estimation method is run at the country-sector level (exploiting heterogeneity *within* a given country-sector pair), it implicitly assumes that transport costs are independent *across* sectors and *across* origin countries. In plain words, it assumes that transport costs of say, cars, have nothing in common whether those goods come from France or from Germany; or that transport costs that apply to imported goods from France have no common component across sectors. This is a disputable assumption. From a statistical point of view, it implies leaving aside information contained in the fact that transport costs have a both a country-specific component and a sector-specific component. We believe that explains the better accuracy of the baseline estimation.

All these elements, in particular Concern 2 regarding the lower accuracy of the estimates, drive us to maintain our original estimation as baseline method in the revised version. However, we also want to keep track of this alternative method as further robustness check. For this purpose, we have amended the online Appendix with a section devoted to the referee's method (Section D.3).

2.1.3 Concerns about endogeneity

***The endogeneity problem**: quoting Footnote 14 of the paper, the authors are estimating* t_i *and* $t_{s(k)}$ *as coefficients on the industry or country dummies times* $1/\widetilde{p}_{ik}$. *[...] Based on the productivity-sorting model in Melitz (2003) or the quality-sorting model in Baldwin and Harrigan (2010),* $1/\widetilde{p}_{ik}$ *is either positively or negatively correlated with* ϵ_{ik}. *So, the NNLS estimates are biased; and the bias has nothing to with the casual versus accounting interpretation of the estimates. Accordingly, the one-line justification the authors provide to not address the endogeneity problem is far from convincing.*

Indeed, this is a very important point. The referee states that, based on theoretical insights by Mélitz (2003) or Baldwin & Harrigan (2011), $1/\widetilde{p}_{ik}$ is correlated in one direction on another with residuals ϵ_{ik}. In other words, more productive firms and/or firms selling high-quality products will charge systematically different prices, all other things equal – in our case, for a given country-product pair.

We obviously do not question this conceptual issue. However, it is worth noting that a good deal of the bias (such as the part relating to the quality effect) is going to appear identically in the CIF (p) and the FAS ($\widetilde{p}_{ik}$) prices. Consequently, since our dependent variable is based on a ratio between the former and the latter, the (reverse causality) bias cancels out. That said, the possibility remains that bigger firms may impact transport costs, due to their ability of bargaining discounts for larger shipped volumes. In presence of pricing-to-market behavior of firms (see Krugman, 1987), the export price set by the firm ($\widetilde{p}_{ik}$) may also be partly endogenous to the size of transport costs if for instance, the exporting firm absorbs (part of) the transport costs by reducing the fas price.

Following the referee's advice, we therefore decided to provide a full set of IV estimates to provide a clean assessment of the size of the potential bias. Section 3.3.2 in the revised version of the paper provides an overview of the results, while section B.3 in Appendix B provides a full presentation of the theoretical basis for the first-stage equation, as well as first-stage estimates. We follow earlier literature (see e.g. Caliendo and Parro, 2015, or Lashkaripour, 2017) by implementing a first-stage equation regressing the fas price $\widetilde{p}$ on custom duties based on tariffs at the product line, together with one-year lagged fas prices. First-stage estimates reported in section B.3 show that our main instrumental variable displays the right statistical properties, and that we can confidently re-inject the predictions arising from the first-stage equation for $\widetilde{p}_{ik}$ on the right-hand side of our estimated equation (Equation (9) in the paper) to produce a 2SLS-type of estimation. Figure 4 in the revised version of the paper reports our benchmark estimates by transport mode, together with their instrumented counterparts. In all cases, these estimates are very similar. This suggests that our baseline estimates do not suffer any substantial biases arising from endogeneity concerns.

It should be noted that we performed this check on our main dataset (SITC 5 digit), and also at the HS 10 level, to handle simultaneously the referee's concern about aggregation issues. In the latter case, second-stage estimates are not reported for the sake of space, but do not change anything to previous conclusion - they are very similar to their non-IV, least squares counterparts. Needless to say that these results are available upon request.

2.1.4 The aggregation problem

The aggregation problem*: The original annual Census data reports trade at the origin country-HS10 product-district level of aggregation, whereas the authors are aggregating up the data even further to the origin country-HS5 industry-year level. Such an aggregation comes with strong implicit assumptions and sacrifices a lot of useful variation in the data. The authors are motivating the aggregation by stating that the problem would become computationally expensive without it. But this reasoning brings us back to my original point* *that the authors can use the Hummels' Methodology to circumvent the computational burden.*

It is true that the original annual Census data reports trade at the origin country-HS 10 product-district level of aggregation. Our initial choice of retaining $s = 3$ at the sectoral level, $k = 5$ at the product level was driven by the use of Hummels' dataset available over 1974-2004 with $k = 5$ the finest degree of aggregation. We agree with the referee that jumping from $k = 10$ to $k = 5$ digits at the product level is detrimental to our ability to exploit useful variations in the data. After checking with the US Bureau of Census, HS-10 data is only available from 1989 until 2019. As previously mentioned, due to the Covid situation, it was further only possible to receive the data over the years 1997-1999 and from 2001 onwards. As previously mentioned, we view as important to preserve the historical coverage of our analysis. Accordingly, we decided to maintain the case $s = 3, k = 5$ as baseline, and to run the estimation using 10-digit products as robustness check in the new Section 3.3.3.

Additionally, the computational burden mentioned by the referee is not attributable to the product classification level ($k = 5$ or 10) but rather to the degree of sectoral classification ($s = 3$ or 4) as it conditions the number of fixed effects. This explains why we consider the $s = 4$ digit- sectoral classification level only for some years. We thank the referee for pointing this ambiguity in our paper, which drove us to rewrite the associated paragraph in the revised version of the paper (see Section 3.3.3).

2.2 Critique 2: Calculation of Unit Prices

My second critique concerns the way the authors are calculating the unit prices. The Census data reports the quantity of goods per observation. So, the authors can calculate the unit price as Value/Quantity, which is consistent with how price is modeled in standard trade models. Instead, the authors calculate unit price as Value/Weight. This used to be a common exercise in the past where many data-sets did not report Quantity. But, given their data, there is no justification for the authors to calculate the prices this way.

Calculating the unit price as Value/Weight presents the authors with an additional endogeneity problem. To elaborate, let $\omega_{ik} = Weight/Quantity$ denote the unit weight of the goods in observation ik. [...] There is evidence that (i) ω_{ik} varies significantly within narrowly-defined product categories, and (ii) ω_{ik} is negatively correlated with transport costs. So the way the authors are calculating unit prices and estimating the model creates a new (but avoidable) source of endogeneity.

Our answer: The referee definitely raised a very important point here, and indeed, Census data do report the quantity of goods (and sometimes even two quantities). In this context, the findings in Lashkaripour (2020) are specifically enlightening. Based on US data very similar to ours over the period 1995-2015, the paper highlights, among other results, that the unit weight of imported goods is indeed substantially heterogeneous even within narrowly-defined product categories, and that the cost of transportation increases more rapidly with unit weight than the cost of production. Lashkaripour (2020) finds that accounting for the heterogeneity in export unit weights provides evidence in favor of the ad-valorem cost assumption regarding transport costs. This result of transport costs close to be totally ad-valorem contrasts from our own findings of additive costs representing 30 to 45% of total costs. There are several explanations for this difference. Beyond a longer time span, our database is exhaustive, and encompasses all goods and industries, while Lashkaripour (2020) restricts to indivisible/discrete goods that represent a bit more 56% of US total imports of goods in his dataset. In this regard, when comparing Tables 1 and 10 in Lashkaripour (2020), one can see that the share of multiplicative costs tends to decrease with the share of discrete goods. It is therefore reasonable to think that the inclusion of all goods, like in our setting, would move the average share of multiplicative costs away from 100%.

Nevertheless, considering the importance of the referee's remark, we went beyond this very first argument to investigate this question in depth. We first discuss data and estimation difficulties before giving the results. At a more fundamental level, we argue that looking at transport costs on a per-weight basis does add relevant information.

2.2.1 Data availability issue

The first difficulty is availability of information on quantities. Neither the US Bureau of Census data nor the 1974-2004 Hummels' data (based on the Census Bureau data) report the quantity by transport mode. This is incompatible with our empirical strategy of estimation which is conditional to the transport mode, as in Hummels (2007). As a result, computing the unit price of all trade flows would require the assumption that the weight per unit is the same for vessel shipments and air shipments at the level of the observation. This is unlikely, as one would expect the higher value-to-weight varieties to be transported by air rather than by vessel. The alternative is to consider only single-mode flows. In Hummels' data (1974-2014), on average 41.1 % of trade flows and 79% of trade value are multi-mode. This would reduce the total value of the sample from 12,500 billion dollars to 2,650 billion dollars, entailing a large loss of useful information. Original Census data, when accessible, are more promising.[5] In 2019, multi-modal flows are 570 billion dollars out of 1,790 billion dollars, or 31% of the data. This is still a large share, but not too large to preclude any work. Accordingly, we dig deeper into this issue with the US Census dataset, restricted to single transport mode flows.

Quantity units are a second difficulty. The Census data remain silent on that matter. To the best of our knowledge, these can only be found in the "Harmonized Tariff Schedule of the United States". Unfortunately, these schedules change many times per year and only the schedules from 2009 onwards are available in a .csv format on the Census website. On the years for which the match could be done (from 2009), it turns out that at our sector level (3-digit), goods (either at the 5-digit or the 10-digit level) are measured in different units. In 2019, only 125 3-digit sectors out of 230 are measured in a single unit

[5] Original Census data are reported at the HS-10 digit $\times$ district of entry $\times$ district of unloading $\times$ rate provision code.

(after cleaning up the unit names[6]).[7] Neglecting these differences would invalidate our functional forms, as no one expects the transport cost of a "piece" to be the same as the transport cost of a "kg", even in the same sector. So we are limited to using quantity units from 2009 to 2019, amending our structure of fixed effects to consider the triplet (origin country, sector, quantity unit).

2.2.2 Estimation issue

We also faced another difficulty in adapting our equation to per-unit rather than per-weight prices. As discussed above, in our baseline regression we separate each transport cost component in two distinct sector-country dimensions. As in Irarrazabal et al. (2015), we assume an additive form for the additive cost, i.e. $t_{is(k)} = t_i + t_{s(k)}$ with i the origin country and s the sector. In the specific case of quantities, this raises a non-trivial issue for country-level fixed effects. Sector-level fixed effects could be easily replaced by (**sector, quantity unit** ou **sector** $\times$ **quantity unit**) fixed effects; but the same does not appear possible for country fixed effects. Let us elaborate on this issue. Let us develop the reasoning in more details.

In the per-weight price, the existence of a single country fixed effect applicable to all sectors is justified, as a kilogram is always a kilogram and one can assume they both add the same to transport costs from, say, Germany. In contrast, an unit of tee-shirt is quite different from an unit of car. To clarify this point, consider imports of tee-shirts and cars from Germany and China. Under the separability assumption, importing a tee-shirt from either country implies paying the cost given by the country fixed effect (the same for all sectors) plus the cost given by the sector fixed effect; and similarly for importing a car. Hence, the difference in the cost of importing a car from Germany versus China would be the same, in dollars, as the difference between the cost of importing a tee-shirt from Germany relative to China. This does not seem a sensible assumption. In this setting, we cannot keep the separability assumption. As discussed before, this dramatically increases the computational difficulty of our method (with no substantial different results, see Subsection 3.3.1. in the main paper).

Integrating these various constraints, we run the robustness check (weight versus quantity) *i)* on a sample reduced over 2009-2019, considering single transport mode flows - amounting to 66% of the value of the baseline sample; *ii)* retaining a non-separable structure of three-dimensional fixed effects $t_{is(k)u}$, $\tau_{is(k)u}$ according to the following equation:

$$\ln\left(\frac{p_{iku}}{\widetilde{p}_{iku}} - 1\right) = \ln\left(\tau_{is(k)u} - 1 + \frac{t_{is(k)u}}{\widetilde{p}_{iku}}\right) + \epsilon_{iku}$$

[6] As units are not always coherent (eg weight can be given in "kg", "kg." "Kg" and, also, "g" and "t").

[7] For instance, 3-digit SITC sector "061 Sugar, molasses and honey" includes among other products, 5-digit SITC product "6150 Molasses, whether or not decolourized", measured in liters and 5-digit SITC product "06160 Natural Honey" measured in kg. Actually worse than this, the 5-digit SITC product "06190 Other sugars; sugar syrups; artificial honey (whether or not mixed with natural honey); caramel" includes both 10-digit HTS product "1702903500 Other: invert molasses", measured in liters and 10-digit HTS product "1702602200 Blended syrups described in additional u.s. note 4 to chapter 17: described in general note 15 of the tariff schedule and entered pursuant to its provisions" measured in kg.

where p_{iku} refers to the cif price associated with the quantity of good k imported from country i, measured in unit u (e.g. kg or number), $\widetilde{p}_{iku}$ being the corresponding unit value (fas price).

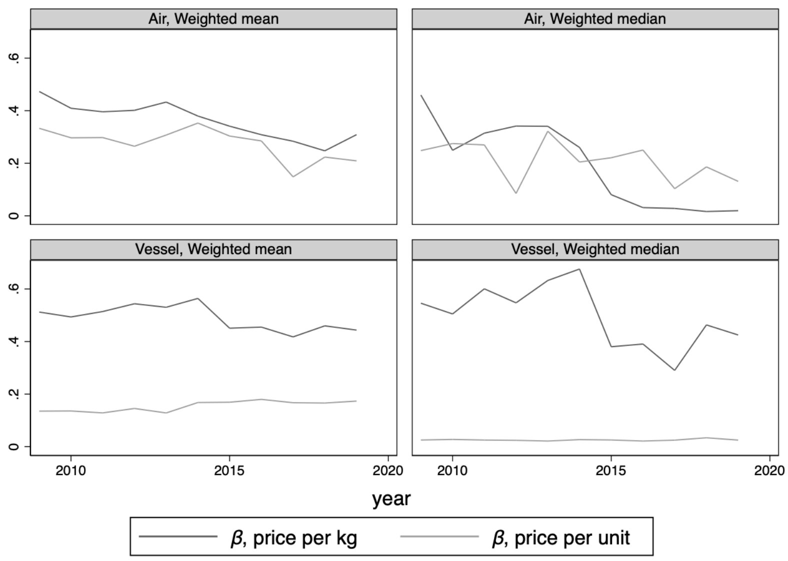
The results are reported in the Online Appendix D.4, as well as here in Table 2 and in Figure 2 for reading convenience. In Table 2, for each transport mode, the first column reports the estimation based on the price per quantity, the second column reports the results obtained considering the price per kg on the same (limited) sample and the last column reports our baseline results on the large sample (considering the average value over 2005-2019, under the separability assumption).

Table 2: Comparison: Price per quantity versus per kg, 2009-2019

Mode:	Air			Vessel		
Price per:	Qy	Kg	Kg	Qy	Kg	Kg
Sample	Limited	Limited	Baseline	Limited	Limited	Baseline
# of sectors	22	22	216	60	60	225
# of partners	15	15	211	21	21	205
# of pairs	339	339	12,544	1,100	1,100	12,649
Trade value (Bn USD)	242	242	331	583	583	920
Share of additive costs β						
Mean	0.27	0.36	0.22	0.15	0.49	0.45
Median	0.19	0.16	0.17	0.03	0.51	0.44
Std. dev.	0.29	0.39	0.19	0.25	0.29	0.26
Time trend coefficient	-0.049	-0.054	-0.026	0.032	-0.020	-0.022

Notes: Time trend coefficient is the annual growth rate.

Figure 2: β Estimate: Price per quantity or price per kg, 2009-2019



Notes: In both cases, estimation is run without imposing the separability assumption.

Two main results emerge. First, given the previously underlined constraints on the sample selection for quantities, the estimation based on quantity can only be run on a reduced sample. In contrast to the aggregation and the separability issues, these restrictions strongly limit both the number of sectors and of countries covered, and do also impact the value of trade flows covered. In our view, this raises a non-trivial sample selection bias that reduces the general scope of the transport cost estimates. Second, in terms of β estimates, the results clearly show that using price per unit (whatever that unit is) instead of price per weight decreases the share of additive costs (except if one look at the median for air). In this regard, they stand in line with the results of Lashkaripour (2020), and confirm the correlation between weight per unit and unit price. Still, the share of additive cost is not reduced to zero (except if one looks at the median for vessel). Thus these results do not disqualify our approach, especially as we cover a much larger period and sample with our baseline estimate.

2.2.3 On the relevance of the per-weight price approach

At a more fundamental level, we do believe that the study of transport costs measured on a per-weight price adds some relevant information on the international transport cost burden faced by exporters. Let us explain why.

Our main objective is to provide a quantitative assessment of the international transport costs burden over time; on that matter, one may start with the observation that transport cost schedules are expressed through a mixed per-weight and per-volume basis, both historically and nowadays. For example, in 2021, air freight trade costs are expressed in weights, with a minimal weight per volume ("volumetric weight" or "dimensional weight")[8] while maritime freight costs are expressed in volume. Hence, looking at per-kg transport cost can be interpreted straightforwardly as trying to estimate the actual existing shipping costs, with sector fixed effects interpretable as measure of mean density for different sectors. The existence of per-volume or per-weight shipping cost is directly linked to the technical constraints of the transportation sector, hence exogenous to exporting firms' decisions. In contrast, per-unit shipping cost depends on the behavior of exporting firms. Put differently, the shipping cost per weight is one of the exogenous parameters firms take into account in their production choices, including weight per unit. Accordingly, studying the technical per-volume or per-weight shipping cost is interesting to understand the context in which firms operate.

In a related manner, restricting the sample to denumerable goods would defeat our purpose of estimating international transport costs for the whole range of US imports. This argument is illustrated by Figure D.6 in the online appendix (replicated here with Figure 3). After computing the share of discrete goods per 5-digit SITC import in 2009, we have used the changing composition of US imports to approximate the share of discrete goods in the total value of US imports on a yearly basis. According to this rough approximation, discrete goods are between 23% and 52% of US imports, reaching a value above 50% for only two years. Switching to a per-unit approach would hence mean a marked reduction

[8] See for example https://transporteca.co.uk/shipping-costs, http://wap.dhl.com/serv/volweight.html and https://en.wikipedia.org/wiki/Dimensional_weight).

in the trade flows coverage, thereby limiting the general scope of our estimates.

Figure 3: Estimated share of discrete goods in US imports, 1974-2019

Based on the share of discrete goods in the value of each 5-digit sitc import in 2009.
1977 not reported (the number is very small)

After considering all the above arguments in depth, we decided not to switch the paper from the study of price per weight to the study of price per quantity. We thus maintained our original empirical strategy covering the whole period 1974-2019 in the revised version, while we extended the Online Appendix with this supplementary robustness check. We hope to have convinced you that this is a relevant choice.

2.3 Critique 3: Big Picture Implications

My third critique concerns the lack of an exciting punchline. The fact that composition effects have not countervailed the reduction in pure transport costs (at least not as much as previously believed) is an interesting but minor observation. Does this observation revise our understanding of say the gains from trade? Does it shed new light on a puzzle many people are thinking about? One crude suggestion is to see how the reduction in the industry-specific cost terms is related to the industry-level trade elasticities. If the composition effects favor low-elasticity industries, the findings in the paper may have first-order implications for the gains from trade. Another suggestion is to dig deeper into the relative rate at which additive and multiplicative transport costs have declined over time. Since additive transport costs favor rich (high-quality exporting) countries, the disproportionally greater reduction in additive costs can perhaps explain the rise of low-income exporter as documented by Hanson (2012, JEP).

Our answer: We devoted a lot of thought to this point, which directly echoed a similar concern by the other referee. Taking stock of your suggestion, we decided to offer insights on the welfare implications of our results. The new section 5 "The role of additive cost: Theoretical insights" is devoted to a theory-based analysis of the alterations to welfare gains involved by the relative variations of additive and multiplicative transport costs over our period of analysis. To do so, we start from the canonical Mélitz's (2003) model where we add additive trade costs. The inclusion of additive costs in a New Trade model has already been performed in Sorensen (2014) and Irarrazabal et al. (2015). However, Sorensen (2014) exclusively provides a theoretical analysis, without any quantitative exercise. In a version of the Chaney (2008) model amended for additive costs, Irarrazabal et al. (2015) perform a quantitative simulation to assess the welfare variations induced by the increase in such additive costs (vs ad-valorem costs). For this, they rely on a calibration for trade costs based on their single-year estimation (for the year 2004), from which they depart by assuming an ad-hoc assumption (specifically, a 5% increase in the ratio of additive cost to the median fas price). In contrast, our own exercise relies on a several decades of US data. It allows us to assess the welfare changes induced over time by the relative dynamics of additive and multiplicative costs, based on the values actually observed in the data over the period 1974-2019 in all their dimensions (additive and ad-valorem).[9]

In the new Section 5, we use our estimation results over 1974-2019 (Section 3 of the paper) to implement several comparative statics exercises to investigate the different welfare consequences of alterations to multiplicative and additive costs. In addition, we also assess how the latter results are affected by changes in sunk costs of exports f_x. To that end, we adjust the share of exporting firms in the US, based on Bernard et al. (2003) and Lincoln & McCallum (2018). In our preferred exercise, we quantify the welfare gains deriving from the joined reduction in the fixed export cost f_x and in the variable transport costs as documented in Section 3 (where the two additive/ad-valorem components decrease). We contrast this with the case where the reduction of total transport costs is solely attributed to a decrease in ad-valorem costs.

Table 6 in Section 5 of the paper reports the results of these various comparative statics exercises for Air and Vessel transport modes. Specifically, we report the welfare effect of a change in variable transport costs, under both scenarios of a constant and fixed export cost. In our preferred scenario, the reduction in variable transport costs in Air transport generates a 40% higher welfare gain when such a reduction partly occurs through the additive component, rather than when it happens through a decrease in ad-valorem costs only. In vessel transport, the extra welfare gains due to the joined reduction of both transport costs components are more modest, with a magnitude of order of 14%.

Overall, these results add a substantial contribution to the paper: we are able to provide a quantitative assessment of the welfare gains induced by the decrease in both types (additive and multiplicative) of costs over a 45-year period covering a moment of unprecedented acceleration in international trade, and to highlight the respective part of each component in the determination of these gains.

[9] On a more positive side, our methodology allows for the identification of both multiplicative and additive costs as a share of total costs, whereas additive costs in Irarrazabal et al. (2015) are expressed relatively to the product of prices and multiplicative costs.

References

Baldwin, R. & Harrigan, J. (2011). Zeros, Quality, and Space: Trade Theory and Trade Evidence. *American Economic Journal: Microeconomics*, 3(2), 60–88.

Bernard, A. B., Eaton, J. J., Jensen, B., & Kortum, S. (2003). Plants and productivity in international trade. *American Economic Review*, 93(4), 1268–1290.

Chaney, T. (2008). Distorted gravity: The intensive and extensive margins of international trade. *American Economic Review*, Forthcoming.

Hummels, D. (2007). Transportation costs and international trade in the second era of globalization. *Journal of Economic Perspectives*, 21(3), 131–154.

Irarrazabal, A., Moxnes, A., & Opromolla, L. D. (2015). The tip of the iceberg: A quantitative framework for estimating trade costs. *The Review of Economics and Statistics*, 97(4), 777–792.

Lashkaripour, A. (2020). Weight-based quality specialization. *Journal of International Economics*, 127, 103380.

Lincoln, W. F. & McCallum, A. H. (2018). The rise of exporting by u.s. firms. *European Economic Review*, 102, 280–297.

Mélitz, M. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. *Econometrica*, 71(6), 1695–1725.

Sorensen, A. (2014). Additive versus multiplicative trade costs and the gains from trade. *Canadian Journal of Economics*, 47(3), 1032–1046.