The Deviation Terms in the Decomposition of Aggregate Productivity Growth

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In the decomposition of aggregate productivity growth, corresponding components are generally indexed according to the deviation of individual-level productivity from aggregate productivity. This paper provides an alternative perspective and points out that this decomposition method seems more suitable for studying change in relative aggregate productivity growth than for aggregate productivity growth when a deviation term is adopted.

Keywords: Growth decomposition, Aggregate productivity, Deviation term, Within and between effects

JEL Classification: O47

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I. Introduction

Many empirical studies[1] use firm-level data in investigating aggregate consequence on industry-level productivity from the perspective of heterogeneous individual firm dynamics. Some of these studies decompose industry-level productivity growth over time into components that reflect changes in firm-level productivity and the reallocation of shares among continuing, entering, *and* exiting firms.[2]

In previous studies, industry-level productivity is usually proxied by industry productivity, which is defined as the weighted average of firm productivity. Baily *et al.* (1992) proposed a method for decomposing change in industry productivity into components indexed by firm productivity. Furthermore, Haltiwanger (1997) suggested a modification and proposed the decomposition of the same change into components indexed by firm relative productivity, a deviation term related to firm productivity. However, as we will discuss, this modified decomposition method is more compatible with a case in which industry-level productivity is proxied by industry relative productivity, which is the weighted average of firm relative productivity. Thus, using this modified method in decomposing change in industry productivity is arguably problematic. Notably, the same argument can be applied to the decomposition of change in industry-level productivity when change in industry heterogeneity is considered (Dosi *et al.* forthcoming). That is, industry or firm productivity is measured geometrically in a zonotope (Dosi *et al.* 2016).

The paper proceeds as follows: Section 2 discusses two measures for industry-level productivity and its growth. In Section 3, we introduce two decomposition methods suggested by Baily *et al.* (1992) and Haltiwanger (1997) for change in *industry productivity*, and a decomposition method used when *industry relative productivity* is

[1] With Baily *et al.* 1992; Haltiwanger 1997; Bartelsman and Dhrymes 1998; Dwyer 1998; Bartelsman and Doms 2000; Baily *et al.*(2001); Decker *et al.* 2017 using data from US, Disney *et al.* (2003) from UK, Griliches and Regev 1995 from Israel, Dosi *et al.* 2015 from France, Germany, and UK, and Bloom *et al.* (2016); Ding *et al.* (2016) Brandt *et al.* (2017) from China.

[2] In this paper, we follow the frameworks proposed by Baily et al. 1992; Griliches and Regev 1995. The decomposition focusing only continuing firms proposed is not under our discussion.

adopted as the proxy. Finally, in Section 4, we will discuss these decomposition methods in detail and provide empirical evidence to demonstrate our argument.

II. Two Measures for Industry-level Productivity and Its Growth

To proxy industry-level productivity, previous studies usually define *industry productivity* at time *t*, denoted by P^t, as the weighted average of *firm productivity*, that is,

$$P^t := \sum_{i \in I^t} w_i^t p_i^t \tag{1}$$

where $p_i^t \in \mathbb{R}$ and $w_i^t \in \mathbb{R}$ represent the *firm productivity* and *market share* of firm *i* at time *t*, respectively, and I^t, denotes the set of all firms in one industry at time *t*. Thus, industry-level productivity growth from time t_1 to t_2 is measured according to change in *industry productivity* over two time periods *i.e.* $\Delta P = P^{t_2} - P^{t_1}$.[3]

Notably, the magnitude of *firm productivity* p_i^t indicates the output per unit input and many empirical studies use total factor productivity or labor productivity as its proxy. However, it is also interesting to understand firm's productivity in a relative term. Compared to the reference level, how much more or less output one firm produces given the same unit input. We thus define *firm relative productivity* of firm *i* at time *t*, which is denoted by $\hat{p}_i^t$:

$$\hat{p}_i^t := p_i^t - K^t \tag{2}$$

where $K^t \in \mathbb{R}$ representing the reference value at time *t*. *Firm relative productivity* $\hat{p}_i^t$ is a useful index. The reference value at time *t* has a specific value as a benchmark. Here, given that we are discussing a general case, we use a generic term that can be replaced by a specific benchmark according to the research topic under consideration. Crozet and Trionfetti (2013) constructed an index of firm's comparative

[3] The symbol $\Delta_{t_1}^{t_2}$ denotes difference between the times t_2 and t_1 of the variable under consideration, *i.e.*, $\Delta_{t_1}^{t_2} x = x^{t_2} - x^{t_1}$, unless differently specified. To simplify the notation, we will use Δ instead of $\Delta_{t_1}^{t_2}$ when no confusion arises.

advantage including *firm relative productivity* and performed regression analyses with *firm relative productivity* as an important independent variable.[4] *Firm relative productivity* is also similar to the distance-to-the-frontier measure used in the literature related to "iron law of convergence".[5] Rodrik (2013) and Bartelsman *et al.* (2008) have provided details at the industry and firm levels, respectively. On the basis of *firm relative productivity*, we define *industry relative productivity* at time *t*, denoted by $\hat{P}^t$, as

$$\hat{P}^t := \sum_{i \in I^t} w_i^t \hat{p}_i^t \tag{3}$$

Correspondingly, we use $\Delta\hat{P}$, that is, the dfference of *industry relative productivity* from time t_1 to t_2, to measure industry-level productivity growth.

Remark In general, $P^t = \hat{P}^t$ only when $K^t = 0$; as a result, $\Delta P = \Delta\hat{P}$ only when $K^{t_1} = K^{t_2}$.[6] However, even when $K^{t_1} = K^{t_2}$ and thus $\Delta P = \Delta\hat{P}$, ΔP is not equivalent to $\Delta\hat{P}$. Conceptually, ΔP represents change in *industry productivity*, and $\Delta\hat{P}$ represents change in *industry relative productivity*. We cannot conclude the equivalence of two quantities when only their dfferences over time are equal. For example, even if $2 - 1 = 100 - 99$, the quantities involved are different. We will address this point in detail in Section 3 and draw our conclusions in Section 4.

III. Decomposition of the Industry-Level Productivity Growth

In this section, we introduce the decomposition of changes in *industry productivity* (Subsection 3.A) and *industry relative productivity* (Subsection 3.B).

[4] Precisely speaking, they define their relative productivity as the ratio, *i.e.* $\frac{p_i^t}{K^t}$ not dfference.

[5] They generally define the distance as $K^t - p_i^t$ if $p_i^t < K^t$.

[6] By substituting Eq. 2 into Eq. 3and by condition $\Sigma_{i \in I^t} w_i^t = 1$, we have

$$\hat{P}^t = \sum_{i \in I^t} w_i^t \left(p_i^t - K^t \right) = \sum_{i \in I^t} w_i^t p_i^t - K^t \sum_{i \in I^t} w_i^t = P^t - K^t$$

i.e. $P^t = \hat{P}^t$ if and only if $K^t = 0$ and $\Delta\hat{P} = (P^{t_2} - K^{t_2}) - (P^{t_1} - K^{t_1}) = (P^{t_2} - P^{t_1}) - (K^{t_2} - K^{t_1}) = \Delta P - \Delta K$, *i.e.* if and only if $\Delta K = 0$.

A. Decomposition of Change in Industry Productivity

On the basis of the decomposition introduced in Equation (3), we can decompose ΔP as follows:[7]

$$\Delta P = \underbrace{\sum_{i \in C} w_i^{t_1} \Delta p_i}_{\text{fixed shares}} + \underbrace{\sum_{i \in C} p_i^{t_2} \Delta w_i}_{\text{share effect}} + \underbrace{\sum_{i \in N} w_i^{t_2} p_i^{t_2} - \sum_{i \in X} w_i^{t_1} p_i^{t_1}}_{\text{entry and exit}} \tag{4}$$

where C denotes continuing firms that are active at t_1 and t_2, N denotes entering firms that are active only at time t_2, X denotes exiting firms that are active only at t_1, and ΔP is decomposed into three components. The first term, originally called "fixed shares," represents a within-firm component based on Firm-level productivity changes, which are weighted by initial shares in the industry. The second term, originally called "share effect," represents a between-firm component that reflects changing shares, which are weighted by ending *firm productivity*. The last term represents the contributions of entering and exiting firms.[8]

BHC decomposition With regard to the decomposition in Equation (4), Haltiwanger (1997) argued that the "share effect" indeed captures the between-plant and the covariance terms by using *firm productivity* at the ending time in this effect and thus suggests the modification of the decomposition in Equation (4).

$$\Delta P = \underbrace{\sum_{i \in C} w_i^{t_1} \Delta p_i}_{within-plant} + \underbrace{\sum_{i \in C} p_i^{t_1} \Delta w_i}_{between-plant} + \underbrace{\sum_{i \in C} \Delta p_i \Delta w_i}_{\text{cov}\, ariance} + \underbrace{\sum_{i \in N} w_i^{t_2} p_i^{t_2} - \sum_{i \in X} w_i^{t_1} p_i^{t_1}}_{net-entry} \tag{5}$$

where the "within-plant" and "net-entry" terms are the same as the "fixed shares" and "entry and exit" components in (4), respectively. Hereafter, we refer to the right-hand side of Equation (5) as the BHC decomposition.

Haltiwanger decomposition (Haltiwanger 1997) continues to point out that the "between-plant" and "net-entry" terms in (5) do not clarify the

[7] Griliches and Regev (1995) proposed an alternative decomposition method. Our main argument in this note applies to their framework.

[8] McMillan and Rodrik (2011) proposed the same framework without the "entry and exit" term at the aggregate level. They studied aggregate consequence on labor productivity in an economy according to the dynamics of different economic sectors, for example, Vries *et al.* (2015) and Diao *et al.* (2019), based on several developing countries.

deviation of relevant firm-level productivity from initial industry-level productivity. Eventually, he proposes an alternative decomposition of ΔP as

$$\Delta P = \underbrace{\sum_{i\in C} w_i^{t_1}\Delta p_i}_{within-plant} + \underbrace{\sum_{i\in C}\left(p_i^{t_1} - P^{t_1}\right)\Delta w_i}_{between-plant} + \underbrace{\sum_{i\in C}\Delta p_i \Delta w_i}_{covariance} + \underbrace{\sum_{i\in N} w_i^{t_2}(p_i^{t_2} - P^{t_1}) - \sum_{i\in X} w_i^{t_1}(p_i^{t_1} - P^{t_1})}_{net-entry} \quad (6)$$

which is exactly the decomposition method adopted in many empirical studies (Haltiwanger 1997; Bartelsman and Doms 2000; Foster *et al.* (2001); Disney *et al.* (2003); Ahn *et al.* (2004); Bloom *et al.* (2016); Ding *et al.* (2016)). In contrast to the BHC decomposition, the Haltiwanger decomposition retains the transitivity of indices. Thus, the Haltiwanger decomposition is more competitive in studies that considered the transitivity of indices (Good *et al.* (1999); Rhee and Pyo(2010). Finally, given that $\sum_{i\in I^{t_1}} w_i^{t_1} = \sum_{i\in I^{t_2}} w_i^{t_2} = 1,$ Equation (6) is obtained from (5) by removing the zero quantity

$$P^{t_1}\left(\sum_{i\in I^{t_2}} w_i^{t_2} - \sum_{i\in I^{t_1}} w_i^{t_1}\right) = P^{t_1}\left(\sum_{i\in C}\Delta w_i + \sum_{i\in N} w_i^{t_2} - \sum_{i\in X} w_i^{t_1}\right)$$

and re-collecting terms with a different method. Hereafter, we refer to the right-hand side of equality in (6) as the Haltiwanger decomposition.

B. Decomposition of Change in Industry Relative Productivity

Similar to the method we used to obtain decomposition in Equation (5), we decompose $\Delta\hat{P}$, the change in *industry relative productivity* from time t_1 to t_2 as

$$\Delta\hat{P} = \underbrace{\sum_{i\in C} w_i^{t_1}\Delta\hat{p}_i}_{within-plant} + \underbrace{\sum_{i\in C}\hat{p}_i^{t_1}\Delta w_i}_{between-plant} + \underbrace{\sum_{i\in C}\Delta\hat{p}_i\Delta w_i}_{covariance} + \underbrace{\sum_{i\in N} w_i^{t_2}\hat{p}_i^{t_2} - \sum_{i\in X} w_i^{t_1}\hat{p}_i^{t_1}}_{net-entry} \quad (7)$$

and by substituting (2) into (7), we have

$$\Delta\hat{P} = \underbrace{\sum_{i\in C} w_i^{t_1}\left(\Delta p_i - \Delta K\right)}_{within-plant} + \underbrace{\sum_{i\in C}\left(p_i^{t_1} - K^{t_1}\right)\Delta w_i}_{between-plant} + \underbrace{\sum_{i\in C}\left(\Delta p_i - \Delta K\right)\Delta w_i}_{\text{cov } ariance} + \underbrace{\sum_{i\in N} w_i^{t_2}(p_i^{t_2} - K^{t_2}) - \sum_{i\in X} w_i^{t_1}(p_i^{t_1} - K^{t_1})}_{net-entry}. \tag{8}$$

A special case where the reference value K^t in (2) at times t_1 and t_2 is assigned as the *industry productivity* at time t_1 , that is, $K^{t_2} = K^{t_1} = P^{t_1}$. Thus, change in *industry relative productivity* decomposes as

$$\Delta\hat{P} = \underbrace{\sum_{i\in C} w_i^{t_1}\Delta p_i}_{within-plant} + \underbrace{\sum_{i\in C}\left(p_i^{t_1} - P^{t_1}\right)\Delta w_i}_{between-plant} + \underbrace{\sum_{i\in C}\Delta p_i \Delta w_i}_{\text{cov } ariance} + \underbrace{\sum_{i\in N} w_i^{t_2}(p_i^{t_2} - P^{t_1}) - \sum_{i\in X} w_i^{t_1}(p_i^{t_1} - P^{t_1})}_{net-entry} \tag{9}$$

where the left-hand is the change in *industry relative productivity* $\Delta\hat{P}$ and the right-hand side is the Haltiwanger decomposition of change in *industry productivity* ΔP in Equation (6). That is, if $K^{t_1} = K^{t_2}$, we have $\Delta\hat{P} = \Delta P$ sharing Haltiwanger decomposition.

IV. Discussion

Haltiwanger decomposition (Subsection 3.A) is used to decompose change in *industry productivity* ΔP. It decomposes change in *industry relative productivity* $\Delta\hat{P}$ when the reference value follows $K^{t_2} = K^{t_1} = P^{t_1}$, as indicated in (9). In Section 2, we argue that ΔP is not equivalent to $\Delta\hat{P}$ even when their values are equal and determining which measure is compatible with Haltiwanger decomposition is necessary. Hence, how to achieve these two types of decomposition should be elaborated.

On the one hand, based on the BHC decomposition of ΔP (as indicated in Equation (5)), Haltiwanger (1997) develops his decomposition, *i.e.*, the Haltiwanger decomposition for ΔP (as indicated in Equation (6)).

On the other hand, we have the decomposition of change in *industry relative productivity* $\Delta\hat{P}$ in (7) based on which we can have the Haltiwanger decomposition for $\Delta\hat{P}$ as in (9). To derive decomposition (9) from Equation (7) as soon as the special case $K^{t_2} = K^{t_1} = P^{t_1}$ is set straightforward, whereas to derive decomposition (6), that is, the Haltiwanger decomposition of ΔP from Equation (5), is less obvious.

Indeed, from (5) to (6), productivity index *firm productivity* in "between-plant" and "net-entry" terms is forcedly replaced with *firm relative productivity*. As a result, the values between these two terms are re-distributed.

When Haltiwanger (1997) first proposed his modification, he argued that if all firms hold their productivity in times t_1 and t_2, BHC decomposition yields a bias toward a positive between-plant term and a negative net-entry term given that the sizes of exiting firms are typically larger than those of entering firms. Disney *et al.* (2003) pointed out that a positive net-entry term is expected if entrants are highly productive and exitors are highly unproductive. However, this condition does not necessarily applies to a case for BHC decomposition when the market share of entrants is suffciently low and that of exitors are sufficiently high.

These two expectations share the same idea. As Bartelsman and Doms (2000) stated, *a continuously operating firm with an increasing share makes a positive contribution to aggregate productivity only if it initially has higher productivity than the industry average. Entering (exiting) plants contribute only if they have lower (higher) productivity than the initial average*. However, this idea itself seems to come from the presumption that firm-level productivity is already proxied by *firm relative productivity*. In other words, we actually do not have sufficient reasons to expect what Haltiwanger (1997) and Disney *et al.* (2003) expect in BHC decomposition in (5), where "between-plant" and "net-entry" terms are indexed by *firm productivity*. Thus, we cannot modify decomposition (5) to (6) by simply introducing a deviation term into "between-plant" and "net-entry" despite that this approach is mathematically plausible. For example, when Melitz and Polanec (2015) derived the decomposition in Equation (6), they defined productivity at the industry level as the weighted average of firm productivity but introduced the weighted average of firm relative productivity for deriving the decomposition.[9] This allows them to get Haltiwanger decomposition

[9] Precisely in this paper, they propose to decompose

$$\Phi_2 - \Phi_1 = \sum_i \left[s_{i2} \left(\varphi_{i2} - \Phi_{REF} \right) - s_{i1} \left(\varphi_{i1} - \Phi_{REF} \right) \right]$$

where s_{it} and φ_{it} represent market share and productivity of firm i at time t respectively, Φ_t is defined as weighted average of φ_{it}, and Φ_{REF} represents the reference level. The right-hand side of this equality indicates that they are by using a method similar to ours to obtain Haltiwanger decomposition in Equation (7).

A. Toy Example

In this subsection, we present a toy example of three-firm dynamic from year 1 to year 2 to illustrate our argument. The toy example assumes one input-one output production, where *firm productivity* is proxied by the ratio of its output over its input and a firm's market share the ratio of its input over the total input at the industry level. Table 1 provides the details of this dynamics. *Industry productivity* P_t increases from 0.55 to 1.2, and the decomposition of this change, that is, ΔP = 0.65 according to the BHC decomposition (5), can be found in the first row of Table 2. As suggested by Disney *et al.* (2003), this decomposition has a negative "net-entry" although we have a highly productive entrant (Firm 3) and a highly unproductive exitor (Firm 1). Table 1 shows that *industry relative productivity* $\hat{P}$ changes from 0 to 0.65. Correspondingly, the second row of Table 2 indicates the decomposition of this increase ($\Delta\hat{P}$ = 0.65) according to Haltiwanger decomposition (9). This decomposition is indexed by *firm relative*

Table 1

Toy Example: Industry-level Productivity Growth Based on Three Firms

	Year 1					Year 2				
	1	2	3	4	5	6	7	8	9	10
Panel A	Input	Output	w_i^1	p_i^1	$\hat{p}_i^1$	Input	Output	w_i^2	p_i^2	$\hat{p}_i^2$
Firm 1	180	90	90%	0.5	-0.05	-	-	-	-	-
Firm 2	20	20	10%	1	0.45	20	20	80%	1	0.45
Firm 3	-	-	-	-	-	5	10	20%	2	1.45
Panel B	Input	Output	$\sum_1^3 w_i^1$	P^1	$\hat{P}^1$	Input	Output	$\sum_1^3 w_i^2$	P^2	$\hat{P}^2$
Industry	200	110	100%	0.55	0	25	30	100%	1.2	0.65

Toy example assumes 1-input-1-output production. In each firm, firm productivity is proxied by the ratio of its output over its input and its market share the ratio of its input over the total input at the industry level. Reference level follows $K^1 = K^2 = P^1$.

actually decomposing, as named in our paper, the change of *industry relative productivity*, although the left hand is called the change of *industry productivity*.

TABLE 2
TOY EXAMPLE: DECOMPOSITION OF THE INDUSTRY-LEVEL PRODUCTIVITY GROWTH

Proxy for Productivity Growth	Method	Within-plant	Between-plant	Covariance	Net-entry
$\Delta P = P^2 - P^1 = 1.2 - 0.55 = 0.65$	(5)	0	0.7	0	-0.05
$\Delta \hat{P} = \hat{P}^2 - \hat{P}^1 = 0.65 - 0 = 0.65$	(9)	0	0.315	0	0.335
$\Delta P = P^2 - P^1 = 1.2 - 0.55 = 0.65$	(6)	0	0.315	0	0.335

productivity, and thus we always have positive "net-entry" term by construction if entrants are more productive than the reference level and exitors are less productive.

In the first case, *firm productivity* is adopted, and thus *industry productivity* is the proxy for firm-level and industry-level productivity. Correspondingly, BHC decomposition is used, which is indexed by *firm productivity*, in decomposing industry-level productivity growth proxied by ΔP. As for the second case, *firm relative productivity* is adopted, and thus *industry relative productivity* is used. Haltiwanger decomposition indexed by *firm relative productivity* is used in decomposing industry-level productivity growth proxied by $\Delta\hat{P}$. We do not have any preference between them. As reported in the third row of Table 2, using Haltiwanger decomposition indexed by *firm relative productivity* in decomposing change in *industry productivity* ΔP is problematic.

B. Empirical Example

Our empirical example uses firm-level data from AMADEUS[10] provided by Bureau van Dijk. It contains balance sheets and income statements of over 21 million European firms from 2004 to 2013. To prevent the potential effect of financial crisis in 2008 and the possibility that exiting firms at 2013 are not real exitors but only those not reported in the dataset in the ending year, we focus on dynamic from 2009 to 2012. For each manufacturing firm in UK,[11] we collect the number of employees and value-added in 2009 and 2012 from the original dataset to proxy

[10] The edition at our access is October 2015.

[11] Manufacturing industries are usually targeted by previous studies. See the Table 8.1 in Foster *et al.* (2001). Similar exercises can be done for other main European countries. The results are available upon request.

TABLE 3

DECOMPOSITION OF THE INDUSTRY-LEVEL PRODUCTIVITY GROWTH FROM 2009 TO 2012–SELECTED MANUFACTURING DIVISIONS IN UK

	1	2	3	4	5	6	7	8	9	10	11	12
Division	P^{2009}	P^{2012}	ΔP	within-plant	between-plant	covariance	net-entry	entrants	exitors	No. of Firms		
	$\hat{P}^{2009}$	$\hat{P}^{2012}$	$\Delta \hat{P}$							C	N	X
Food Product	42.98	47.87	4.89	4.44	-2.82	-0.76	4.02	9.66	5.64	560	223	167
	0	4.89	4.89	4.44	-0.57	-0.76	1.78	1.74	-0.04			
Basic Metals	56.72	48.87	-7.86	2.13	-24.36	-1.54	15.91	24.55	8.64	146	53	42
	0	-7.86	-7.86	2.13	0.62	-1.54	-9.06	-9.96	-0.89			

For each division based on 2-digit NACE, we conduct decomposition (5) for change of industry productivity and decomposition (9) for change of industry relative productivity and report the results respectively in upper and lower of the panel. Notice that for different decomposition, "between-plant", "net-entry", "entrants", and "exitors" are indexed by firm productivity and firm relative productivity respectively. "net-entry" = "entrants" – "exitors".

the input and output. Value-added is measured by thousand euro and deflated at four-digit NACE level. The year 2010 is used as the reference year.[12] We then classify the firms according to the first two digits of their four-digit NACE codes into different manufacturing divisions.[13] Within each division, for t = 2009 and 2012, *firm productivity* p_i^t is proxied by the ratio of value-added to the number of employees, and market share w_i^t is computed according to the number of employees. Thus, we can easily have *industry productivity* P^t, *firm relative productivity* $\hat{p}_i^t$ with reference $K^{2012} = K^{2009} = P^{2009}$, and *industry relative productivity* $\hat{P}^t$.

Table 3 reports the decomposition results for only two divisions: food products and basic metals. In the "food products" division, BHC and Haltiwanger decomposition report the same sign for between-plant and net-entry terms. In general, they report different signs and magnitudes for these two terms, as in the "basic metals" division.[14] Distinguishing

[12] The 4-digit Deflators for specific country are provided by Eurostat (https://ec.europa.eu/eurostat/data/database) access on August 30, 2017.

[13] See the classification of division in NACE Rev. 2 - Statistical classification of economic activities in the European Community (https://publications.europa.eu/s/lFFk).

[14] Results for other divisions with different signs and magnitudes for between-plant and net-entry terms of BHC decomposition and Haltiwanger decomposition are available upon request.

these two decomposition method is essential to empirical studies.

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Declarations

No funding was received for this study.
All authors declare that they have no conflict of interest.
Availability of data and material

We cannot provide the data extracted from AMADEUS database because of confidentiality concerns. Bureau van Dijk can be contacted for access. Nevertheless, using AMADEUS database is not necessary to demonstrate the main argument in this study.

Code availability

The code is available upon request.

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