Geography and the Technique Effect: Evidence from Canada*

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Abstract

The technique effect – the reduction in aggregate pollution emissions due to reductions in the pollution intensity of individual industries – is often interpreted as evidence that countries are getting cleaner because of improvements in how goods and services are produced. We extend the standard decomposition used in previous research to show the technique effect may also capture changes in the geography of economic activity. An empirical application to Canada suggests such changes may be economically important. While the technique effect decreased aggregate Canadian pollution intensity by 18.0% between 2009-2021, if the pollution intensity of production had remained fixed, within-industry shifts in production across Canada would have increased aggregate pollution intensity by over 11%. The technique effect decreased Canadian pollution intensity because these within-industry shifts were accompanied by reductions in pollution intensity that were greatest in provinces that received the largest within-industry reallocation of economic activity.

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1 Introduction

Over the past three-plus decades, many countries have experienced a "cleanup" of production: the quantity of pollution emitted during the production of goods and services has been declining despite increased output. This reduction in the aggregate pollution intensity of production – that is, the level of pollution emitted per unit of output – appears to be due to reductions in the pollution intensity of individual industries (the technique effect) rather than in shifts of economic activity toward industries that are relatively clean (the composition effect).[1] The dominance of the technique effect is often interpreted as evidence countries are getting cleaner due to changes in *how* goods and services are produced. In this paper, we investigate whether the technique effect is also capturing changes in *where* economic activity occurs within a country.

Our starting point is a novel extension of the standard decomposition used in previous research that shows the measured technique effect need not reflect changes in how goods and services are produced, but rather may reflect within-country shifts in where economic activity occurs. Specifically, we show the technique effect can be further decomposed into four distinct regional-level components that reflect changes in the pollution intensity of production in each region the industry operates (hereafter, industry$\times$region), as well as changes from within-industry shifts in economic activity across regions.[2]

We then employ this extended decomposition to study changes in the pollution intensity of Canadian production over the period 2009 to 2021 using detailed industry by region data on greenhouse gas emissions and output. The pollution intensity of Canadian production as a whole fell by 24.6% during this period. Applying the standard decomposition suggests that this decline is primarily due to the technique effect, mirroring the findings from the existing literature. Our estimates indicate that the technique

[1] The primacy of the technique effect has been documented for a number of pollutants and countries, including the United States (Levinson (2009, 2015); Shapiro and Walker (2018); Brunel and Levinson (2022)), the European Union (Brunel (2017)), China (Cole and Zhang (2019); Rodrigue et al. (2022)), Canada (Bruneau and Renzetti (2009), Najjar and Cherniwchan (2021)), Germany (Rottner and von Graevenitz (2024)), India (Barrows and Ollivier (2018)) and others (Grether et al. (2009); Copeland et al. (2022)).

[2] By extending the standard decomposition to allow for shifts in the spatial distribution of economic activity across regions, our work is directly related to recent research (e.g. Cherniwchan et al. (2017), Barrows and Ollivier (2018), Holladay and LaPlue III (2021), Najjar and Cherniwchan (2021), Rodrigue et al. (2022)) that has extended decomposition to allow for within-industry changes due to shifts in economic activity across firms. In principle, our decomposition could be extended to the firm level, but we refrain from doing so due to data limitations. Given that decompositions are accounting identities, employing a firm level decomposition that maps directly to the industry level requires emissions data for the universe of firms in an economy. To the best of our knowledge, no such data exists; previous studies (e.g. Barrows and Ollivier (2018), Holladay and LaPlue III (2021), Rodrigue et al. (2022)) have relied on subsamples of the potential universe of firms in their analyses.

effect reduced aggregate pollution intensity by close to 18.0%, whereas the composition effect decreased aggregate pollution intensity by only 5.0%.[3]

When viewed through the lens of the existing literature, these results suggest Canadian pollution intensity primarily declined because of changes in how goods and services are produced. However, the results from our extended decomposition suggest that the technique effect also captures the effects of changes in where economic activity occurs, i.e., its geography. We find that if the industry×province emission intensities had been held fixed at 2009 levels, then changes in the spatial distribution of industry activity across provinces would have increased aggregate greenhouse gas intensity by 11.5%, a phenomenon we term the *regional reallocation effect*. Why, then, did the technique effect cause Canadian pollution intensity to fall to the extent that it did? The answer appears to lie in what we term the *regional technique* and *regional interaction effects*. Our estimate of the regional technique effect indicates that if the spatial distribution of Canadian production had been held fixed as of 2009, aggregate emission intensity would have declined by just over 15% by 2021 due to within-industry×province reductions in pollution intensity. Our estimate of the regional interaction effect indicates that these reductions were unevenly distributed across Canada; this estimate indicates that the co-movement of within-industry shifts in economic activity and within-industry×province reductions in emission intensity led to an additional 14% reduction in aggregate pollution intensity.[4] Given that Canada has experienced a "cleanup" of production similar to those observed elsewhere, our results suggest that geographic reallocations of economic activity may be important for understanding changes in aggregate pollution around the world.

The remainder of this paper proceeds as follows. Section 2 develops our extension of the standard decomposition, while Section 3 discusses our data and presents our results. Section 4 concludes.

2 Extending the Standard Industry Decomposition

Following Levinson (2009, 2015), decompositions have become the standard approach for investigating the sources of changes in a country's aggregate emissions or aggregate

[3]It is worth noting that the co-movement between changes in the composition of production and changes in the pollution intensity of individual industries – the interaction effect – accounts for the remaining change in aggregate pollution intensity (a reduction of approximately 1.6%). This interaction effect is not typically reported in the existing literature due to the fact that previous studies employ decompositions derived under the assumption that changes in emission intensity are small. See Section 2 for further discussion.

[4]The last element of our extended decomposition, the *regional selection effect*, suggests that the entry and exit of industries from Canadian provinces had no meaningful effect on aggregate pollution intensity.

emission intensity. This method starts from a simple accounting identity that adds up pollution from all N industries observed in an economy:

$$Z_t = \sum_{i \in N} Z_{it} = \sum_{i \in N} X_{it} E_{it} = X_t \sum_{i \in N} \Phi_{it} E_{it} \tag{1}$$

where Z_{it} denotes emissions from industry i at time t, X_{it} is the value of industry output, $\Phi_{it} = X_{it}/X_t$ denotes industry i's share of total output at time t, and $E_{it} = Z_{it}/X_{it}$ denotes the emission intensity of industry i at time t. It follows that aggregate emission intensity can then be written as an output weighted sum of the emission intensities of the industries operating in the economy:

$$E_t = \frac{Z_t}{X_t} = \sum_{i \in N} \Phi_{it} E_{it}. \tag{2}$$

With some algebra, the growth rate of aggregate emission intensity across any two periods t and $t-1$ can be written as:

$$\begin{aligned} \frac{E_t - E_{t-1}}{E_{t-1}} = \sum_{i \in N} \Theta_{it-1} \left[\frac{\Phi_{it} - \Phi_{it-1}}{\Phi_{it-1}} \right] + \sum_{i \in N} \Theta_{it-1} \left[\frac{E_{it} - E_{it-1}}{E_{it-1}} \right] \\ + \sum_{i \in N} \Theta_{it-1} \left[\frac{\Phi_{it} - \Phi_{it-1}}{\Phi_{it-1}} \right] \left[\frac{E_{it} - E_{it-1}}{E_{it-1}} \right] \end{aligned} \tag{3}$$

where $\Theta_{it} = Z_{it}/Z_t$ is industry i's share of total pollution emissions at time t. Equation (3) is a version of the now standard industry decomposition that has been employed elsewhere in the literature.[5] The first term on the right hand side of Equation (3) is the *composition effect* that captures the change in aggregate pollution intensity created by changes in the composition of production, holding the pollution intensity of production fixed. The second term is the *technique effect* that captures changes in aggregate pollution intensity due to changes in the pollution intensity of individual industries, holding the industrial composition of the economy fixed. The last term is the *interaction effect* that captures changes in aggregate emission intensity arising from the co-movement of changes in industrial composition and industry emission intensity.[6]

[5]The typical formulation is typically derived directly from Equation (1) rather than from Equation (2) and focuses on emissions rather than emission intensity. As such, the typical derivation also results in an estimate of the *scale effect*, that is the change in emissions resulting from changes in the total scale of economic output in the economy holding industry emission intensity and the composition of industrial production fixed. As our ultimate goal is in understanding the technique effect, and the two approaches deliver the same formulas for the composition and technique effects, for clarity we focus on Equation (3).

[6]It is worth noting that while previous studies employ discrete decompositions of the form presented in Equation (3) to conduct their empirical analyses, the last term is typically ignored. This is because it has

Standard practice has been to take industry decompositions such as Equation (3) directly to the data to construct estimates of the composition and technique effects. The resulting estimates suggest that the technique effect has been the primary source of reductions in aggregate pollution intensity in many countries around the world and have been interpreted as evidence that aggregate emission intensities are falling primarily due to changes in how production occurs. However, what has traditionally been labeled the technique effect may be capturing the effects of within-country shifts in the spatial distribution of economic activity across regions with different emission intensities, making it difficult to determine if existing estimates of the technique effect actually reflect changes in *how* production occurs, as opposed to changes in *where* it occurs.

To see this explicitly, note that the emission intensity of any individual industry i can be written as a weighted sum of the emission intensities for the industry across all R_{it} regions in which it operates at time t:

$$E_{it} = \sum_{r \in R_{it}} \phi_{irt} e_{irt}. \tag{4}$$

Similar to Equation (2), here $\phi_{irt} = X_{irt}/X_{it}$ is the share of industry i's output that is produced in region r, and $e_{irt} = Z_{irt}/X_{irt}$ is the emission intensity of industry i in region r at time t. With some algebra, the change in industry emission intensity across any two periods t and $t-1$ can be written as:

$$\begin{aligned}\frac{E_{it} - E_{it-1}}{E_{it-1}} = &\sum_{r \in R^C_{it}} \theta_{irt-1} \left[\frac{e_{irt} - e_{irt-1}}{e_{irt-1}}\right] + \sum_{r \in R^C_{it}} \theta_{irt-1} \left[\frac{\phi_{irt} - \phi_{irt-1}}{\phi_{irt-1}}\right] \\ &+ \sum_{r \in R^C_{it}} \theta_{irt-1} \left[\frac{e_{irt} - e_{irt-1}}{e_{irt-1}}\right] \left[\frac{\phi_{irt} - \phi_{irt-1}}{\phi_{irt-1}}\right] + \sum_{r \in R^E_{it}} \theta_{irt} \left[\frac{E_{it}}{E_{it-1}}\right] - \sum_{r \in R^X_{it}} \theta_{irt-1}\end{aligned} \tag{5}$$

where $\theta_{irt} = z_{irt}/Z_{it}$ is region r's share of industry i's pollution at time t, R^C_{it} denotes the set of regions in which industry i operates in at both time t and $t-1$, R^E_{it} denotes the set of regions in which industry i operates in at time t, but not at time $t-1$, and R^X_{it} denotes the set of regions in which industry i operates in at time $t-1$, but not at time t.

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become standard practice to derive the decomposition by totally differentiating Equation (2) which yields:

$$\frac{dE_t}{E_t} = \sum_{i=1}^{N} \Theta_{it} \left[\frac{d\Phi_{it}}{\Phi_{it}}\right] + \sum_{i=1}^{N} \Theta_{it} \left[\frac{dE_{it}}{E_{it}}\right]$$

As in Equation (3), the two terms on the right hand side of the above equation correspond to the composition and technique effects. The last term in Equation (3) arises if one considers potentially large, rather than small, changes in pollution.

Substituting equation (5) into equation (3) yields our extended decomposition:

$$
\begin{aligned}
\frac{E_t - E_{t-1}}{E_{t-1}} &= \sum_{i \in N} \Theta_{it-1} \left[\frac{\Phi_{it} - \Phi_{it-1}}{\Phi_{it-1}} \right] + \sum_{i \in N} \Theta_{it-1} \left[\frac{\Phi_{it} - \Phi_{it-1}}{\Phi_{it-1}} \right] \left[\frac{E_{it} - E_{it-1}}{E_{it-1}} \right] \\
&+ \sum_{i \in N} \Theta_{it-1} \left[\sum_{r \in R^C_{it}} \theta_{irt-1} \left[\frac{e_{irt} - e_{irt-1}}{e_{irt-1}} \right] \right] + \sum_{i \in N} \Theta_{it-1} \left[\sum_{r \in R^C_{it}} \theta_{irt-1} \left[\frac{\phi_{irt} - \phi_{irt-1}}{\phi_{irt-1}} \right] \right] \\
&+ \sum_{i \in N} \Theta_{it-1} \left[\sum_{r \in R^C_{it}} \theta_{irt-1} \left[\frac{e_{irt} - e_{irt-1}}{e_{irt-1}} \right] \left[\frac{\phi_{irt} - \phi_{irt-1}}{\phi_{irt-1}} \right] \right] \\
&+ \sum_{i \in N} \Theta_{it-1} \left[\sum_{r \in R^E_{it}} \theta_{irt} \left[\frac{E_{it}}{E_{it-1}} \right] - \sum_{r \in R^X_{it}} \theta_{irt-1} \right] \qquad (6)
\end{aligned}
$$

As in the standard decomposition given in Equation (3), the first two terms on the right-hand side of Equation (6) capture the composition and interaction effects, respectively. The next four terms arise from decomposing the technique effect. We refer to the third term on the right-hand side of Equation (6) as the *regional technique effect* that reflects the change aggregate pollution intensity due to within industry×region changes in emission intensity holding the regional composition of industrial activity constant, while we refer to the fourth term as the *regional reallocation effect* that captures the change in aggregate pollution intensity due to within-industry shifts in economic activity across regions holding industry×region pollution intensity constant. The fifth term, which we refer to as the *regional interaction effect*, is similar to the interaction effect reported in Equation (3), and captures the change in aggregate emission intensity from the co-movement of within-industry changes in the spatial distribution of economic activity across regions, and changes in industry×region pollution intensity. We refer to the final term as the *regional selection effect* that captures the change in aggregate emission intensity due to the entry and exit of industries from different regions.[7]

As Equation (6) shows, the technique effect need not reflect changes in how production occurs (as captured by the regional technique effect), but rather could result from inter-regional shifts in the distribution of economic activity within the industry (as captured by the regional reallocation, interaction and selection effects). If the technique effect is primarily to changes in how production occurs, then the last three terms of Equation (6) should contribute little to observed changes aggregate pollution intensity.

[7] In principle, the regional selection effect could be separated into a *regional entry effect* and a *regional exit effect* that capture the effects of industries entering and leaving different regions, respectively. We focus on the combined selection effect here for expositional simplicity.

In what follows, we investigate this explicitly by taking Equation (6) directly to the data.

3 Empirical Application

3.1 Data

Employing Equation (3) and Equation (6) to study the sources of changes in aggregate pollution intensity requires data on pollution emissions and output by both industry and region. We obtain these data for Canada over the period 2009-2021 from two databases constructed by Statistics Canada. Our pollution emissions data comes from Statistics Canada (2024b), which reports detailed sub-national (province-level) regional data on the emissions of three greenhouse gasses (carbon dioxide, methane, and nitrous oxide) by industry.[8] Our output data comes from Statistics Canada (2024a), which contains annual province-level data on value added by industry, which we use to construct measures of total value added, industry shares of total value added, and regional shares of industry value added. We combine the two data sets to calculate emission intensity, both by industry and industry-province for 58 industries and 12 provinces (and territories).[9]

One potential caveat bears mentioning. While the data that we use contain the most detailed industry definitions we are aware of while also reporting geographic information, each "industry" that we observe in our data is potentially comprised of many more narrowly defined industries, meaning any within-"industry" change in emission intensity could reflect shifts in economic activity across these narrowly defined industries. As a result, our estimates of both the technique effect and its sub-components could reflect unmeasured changes in industry composition.[10]

3.2 Results

We begin our analysis by using our discrete version of the standard decomposition (Equation (3)) to decompose changes in aggregate emission intensity into composition,

[8] An earlier version of this dataset was used by Bruneau and Renzetti (2009) to study the greenhouse gas intensity of Canadian production over the period 1990-2002. However, these earlier data are not available at the industry$\times$province level, making them unsuitable for our purposes.

[9] It is worth noting that these two datasets are reported using different industry classifications. Statistics Canada (2024b) employs the classification system used in Canada's System of National Accounts, while Statistics Canada (2024a) is reported using the North American Industry Classification System (NAICS). We match the two datasets using a concordance from Statistics Canada, leaving us industries that roughly correspond to three-digit NAICS sub-sectors.

[10] See Levinson (2015) for further discussion of the issue of industry aggregation in the context of the United States.

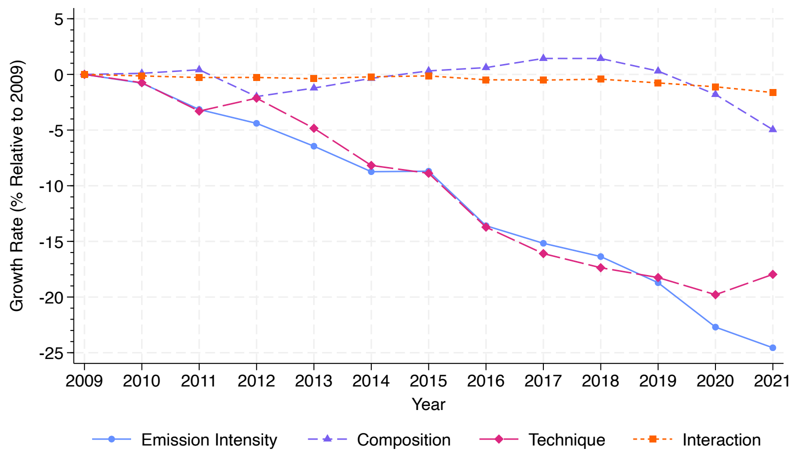

Figure 1: Decomposing Aggregate Emission Intensity

technique and interaction effects. The results from this exercise are reported in Figure 1.

As Figure 1 shows, the aggregate greenhouse gas emission intensity of Canadian production (depicted by the solid line marked by circles) fell by nearly 24.6% between 2009 and 2021. This suggests that Canada has undergone a "cleanup" of production for greenhouse gasses similar to those documented elsewhere. This figure also indicates that this cleanup of Canadian production has primarily been driven by the technique effect. Our estimate of the technique effect (given by the long-dashed line marked with diamonds) indicates that if the composition of Canadian industries had been held fixed as of 2009, aggregate pollution intensity would have declined by close to 18.0% by 2021. In contrast, our estimate of the composition effect (given by the dashed line marked with triangles) suggests that, if the emission intensity of Canadian output had been held fixed at the start of our period of study, aggregate emission intensity would have declined by just under 5.0% over the same period. Our estimates also suggest that the interaction effect (depicted by the short-dashed line marked with squares) arising from reductions in emission intensity in industries that have grown in economic importance over our sample period is small; we find that this interaction caused aggregate emission intensity to decline by just over 1.6% by 2021.

Our finding that the technique effect is the primary determinant of the cleanup of Canadian production mirrors findings for other time periods and pollutants both in Canada (e.g. Najjar and Cherniwchan (2021)), and elsewhere in the world (e.g. Levinson (2009, 2015), Brunel (2017), Cole and Zhang (2019), Copeland et al. (2022)). Next, we apply our extended decomposition given by Equation (6) to examine the extent to which the technique effect is capturing the effects of changes in the geographic distribution of

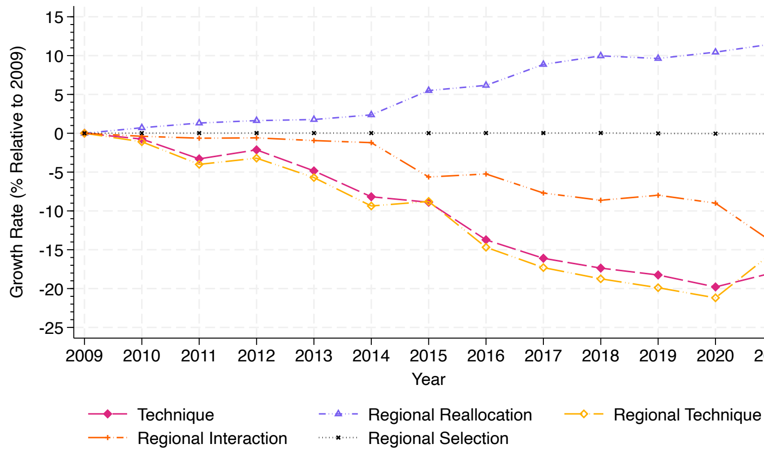

Figure 2: Decomposing The Technique Effect

economic activity across Canada. The results of this exercise are displayed in Figure 2. For the sake of expositional clarity, this figure again displays the technique effect previously reported in Figure 1, as well as the regional technique, reallocation, interaction and selection effects given by the last four terms in Equation (6).

As Figure 2 shows, changes in the geographic distribution of economic activity within industries increased aggregate pollution intensity in Canada. Our estimate of the regional reallocation effect (depicted by the short-dashed dotted line marked with hollow triangles) suggests that there were substantial within-industry shifts in the spatial distribution of economic activity towards relatively emission intensive provinces during our period of study. This estimate suggests that if the regional emission intensity of industry had been held fixed at 2009 levels, then the technique effect would have *increased* aggregate emission intensity by over 11.5% by 2021. Strikingly, this within-industry compositional change is nearly twice the magnitude (in absolute value) of the traditional across-industry composition effect reported in Figure 1.

Why then, did the technique effect reduce aggregate emission intensity to the extent that it did? The answer appears to be the combination of regional technique and regional interaction effects. Our estimate of the regional technique effect (given by the long-dash dotted line marked by hollow diamonds) indicates that if the industry and geographic composition of Canadian output had been held fixed as of 2009, aggregate emission intensity would have declined by just over 15% by the end of our sample period. Moreover, our estimate of the regional interaction effect (depicted by the dash dotted line marked by crosses) shows, as economic activity shifted within-industry towards relatively emission intensive provinces, the emission intensity of these industries in these provinces began to fall. This co-movement of within-industry shifts in economic activity and within-industry×province reductions in emission intensity led to an over 14% reduction in aggregate emission intensity that, when combined with the regional technique effect, more than offset the increase from the regional reallocation effect.

It is also worth noting that the entry and exit of industries from provinces played little role in explaining aggregate emission intensity in Canada between 2009 and 2021. We find that the regional selection effect (depicted in Figure 2 by the dotted lined marked with x's) decreased aggregate emission intensity by less than 0.1% during this period.

4 Concluding Remarks

This paper examines how changes in the geographic distribution of economic activity have contributed to the technique effect. We extend the standard industry-level decomposition that has been used in the existing literature to formally show the technique effect may reflect within-country shifts in the the geography of economic activity and use this extended decomposition to study changes in the pollution intensity of Canadian production over the period 2009 to 2021.

Our analysis suggests that the technique effect is driven, in part, by changes in the geographic distribution of economic activity within industries across regions. Our estimates indicates that if industry×region emission intensity had been held fixed at 2009 levels, within-industry shifts in economic activity towards relatively dirty provinces would have increased the aggregate greenhouse gas intensity of Canadian production by 11.5% by 2021. We find that the technique effect caused Canadian pollution intensity to decline by close to 18% in aggregate because industry×region emission intensity decreased, and these decreases were largest in those industry×regions that also increased in economic importance due to within-industry shifts in economic activity.

While our results provide some initial support for the possibility that the technique effect captures, in part, changes in where production occurs, there are at least two caveats worth mentioning. The first is aggregation. As we noted above, while we are using the most disaggregated data available for Canada that also report geographic information, our estimates of both the technique effect and its sub-components may reflect unmeasured compositional changes. Second, we measure pollution using data on greenhouse gas emissions. As such, our conclusions may not extend to other pollutants. We leave further investigation of these possibilities to future work.

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