Measuring the effects of a carbon tax

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1. Introduction

Climate change will broadly affect the economy. It creates risks for businesses, investors, authorities, and consumers. These risks are most often classified as either *physical risks* or *transition risks*. Physical risks refer to losses associated with increasing severity and frequency of climate events like floods or wildfires. Transition risks refer to losses driven by how firms, households, and governments respond to climate change (e.g., taxes).

Many central banks have recently placed a high priority on understanding how climate change will affect the economy and the financial sector, and especially on how it will affect small banks. In this article, we quantify the effects of a carbon tax, one of the possible climate transition risks for firms, regional economies, and small banks in the US. We study a carbon tax increase of $100 per metric ton of greenhouse gas emissions (measured in CO_2-equivalent units). This tax rate addresses the possibility of a climate policy, but it is broadly in line with the climate literature.

We find that the effects are heavily concentrated in a few sectors. Even though we follow emissions down the production chain all the way to the final demand sector, industries that generate a large fraction of emissions at the source are still among the most affected. For example, Utilities is at the very top of emitting industries both when we consider production linkages and when we do not. The effects are also highly concentrated in a few regions. These regional effects depend crucially on the employment concentration across regions (i.e., how significant are those affected industries for the local economy), but these effects are more widespread when firms can't easily substitute away from inputs that rise in price.

A carbon tax will likely create some challenges for community banks operating in counties with a large share of high-emitting industries. This exercise helps us evaluate government policies in response to climate change, offering a tangible framework to assess the impact of a carbon tax on the corporate sector, the regions where they operate, and small banks in those regions.

2. How a carbon tax affects firm profits

Under a carbon tax, a firm that operates in a high-emitting industry will have to pay a higher tax; and will face reduced future profits.[1] The level of emissions in an industry is a key input for our measure of transition risk (i.e., the effect of the carbon tax on firm profits and firm value) as it captures the degree by which the value of a firm in a particular industry is exposed to the carbon tax. The carbon tax is proportional to carbon emissions at the firm level. This implies that the size of the reduction in profits derives from the degree to which an industry's production is carbon intensive. As we discuss in the next section, our measure of carbon emissions incorporates linkages across industries, so they do not encompass only emissions at the source but also emissions stemming from production inputs.

We quantify transition risk by measuring the decline in the market value of the firm due to the carbon tax. We calculate the decline in the market value of firms using a standard asset pricing model. The value of the firm is the discounted stream of future expected profits.[2] This model considers the possibility of firm default and failure.[3] Carbon emissions at the industry level play a key role but other important components of the model include the industry level volatility and leverage ratio (which is crucial for industries where the decline in the value of equity and debt differs).

We consider the introduction of a permanent $100 carbon tax (per metric ton of greenhouse gas emissions measured in CO2 equivalent units), which lies within current estimates of implied carbon prices that are needed to achieve the proposals in the Paris 2015 agreement. The range of carbon taxes is generally derived from different paths of CO_2

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[1] Firms might move across industries, move production to a different country, or invest in order to reduce emissions. Our estimates abstract from these margins of adjustment. That is, we compute the decline in the value of the firm using the installed production technology.
[2] See Berlin, Byun, D'Erasmo, and Yu (2022) ``Measuring Climate Transition Risk at the Regional Level with an Application to Community Banks'' for a detailed description of the methodology.
[3] We use data on public firms to estimate the parameters of a standard asset pricing model (Merton (1974) `` On the Pricing of Corporate Debt: The Risk Structure of Interest Rates'') as implemented by Bharath and Shumway (2008) `` Forecasting Default with the Merton Distance to Default Model.''

emissions required to achieve a climate goal (e.g., keeping global temperatures from raising above 2° C). We assume that firms' asset value adjusts immediately after the announcement of the tax. As our firm model incorporate the possibility of firm failure results do not necessarily scale up linearly with the carbon tax.

Climate transition risk can affect firms' value not only via changes in carbon taxes but also via a reduced demand for large-carbon-footprint products (changes in consumer preferences that result in a shift in consumer demand for carbon intensive products); technological adaptation toward greener technologies (reducing the value of the technology currently in place and increasing the cost of investment); and firm defaults along the production chain. We abstract from evaluating these factors in our analysis, but with some adjustments our methodology could capture some of these other effects, too.

3. Industry linkages—emission estimates and firm-value losses

The key link between the carbon tax and firm profits are captured by carbon emissions at the industry level. Our estimate of carbon emissions incorporates the fact that an economy is not just a collection of firms producing final goods for consumers, but many products are inputs for other firms. We use an input-output model to account for interactions between firms that produce final goods and firms that produce inputs for other firms.

More specifically, the estimates of carbon intensity at the industry level combine data on emissions at the source and an input-output model to capture production linkages and the extent to which the tax will be paid by the emitting industry or by other industries down the production chain.[4] That is, we use an input-output model to "move" these emissions down the production chain all the way to the final demand sector. The exposure of an industry to the carbon tax (i.e., the tax base) is directly represented by its emission level not only at the source but also by its inputs.

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[4] We use EXIOBASE input-output table and its direct emissions estimates to calculate our measure of emissions. Direct emissions include only those emissions generated in the production stage. The measure of emissions we use incorporate direct emissions for final demand and the emissions that were generated in the production of the firm's inputs.

The input-output model helps us measure the incidence of a carbon tax. "Incidence" refers to who ultimately pays for the tax. For example, if a firm can pass on an entire tax to other firms or consumers through higher prices for its goods, the firm's tax burden is essentially zero. For example, a tax on a power utility can affect the price of electricity used as an input by other firms—even firms that generate very small emissions. This is the case we work with making use of the technology information we obtain from the input-output model. At the other extreme of the results presented here, we could assume that the carbon tax is levied on the emissions at the point of production, and final goods producers face perfectly elastic demand from consumers. If this were the case, the profits of the final good producers would fall one-for-one with the tax and there would be no price effects along the production chain and the effect of the tax can be measured using emissions directly at the source alone.[5]
An input-output model also lets us evaluate a local economic shock's widespread effect when firms can't easily substitute away from an input that has become more expensive.

[Insert Box "Production Model and Emission Estimates" here]

In summary, when we measure the exposure of firm revenues to the carbon tax, we do not rely only on the level of emissions at the source; we also consider the industry linkages. Table 1 presents the top 10 industries ranked by industry losses. Even though our estimates consider industry linkages, several industries that account for a large fraction of emissions at the source are still at the top of our estimates. The most pertinent example is Utilities (221). Losses for this industry are estimated to be 34.1 percent. This industry accounts for about 43.2 percent of emissions at the source (not shown in the table) but *only* 19.4 percent of emissions when industry linkages are considered. At the 3-digit level, Utilities encompass a wide range of energy generation industries. Among them, Fossil Fuel Electric Power Generation accounts for most of the emissions assigned to this industry.

[Insert Table 1: Top 10 Industry by Industry Losses Here]

[5] See Berlin, Byun, D'Erasmo, and Yu (2022) ``Measuring Climate Transition Risk at the Regional Level with an Application to Community Banks'' for a comparison of these two approaches.

4. How a carbon tax affects the rest of the economy

To evaluate the effect of a carbon tax, we must consider regional differences in the economy (which we observe to be significant). For example, a county in the Texas oil patch is more likely to be heavily affected by a carbon tax than a state capital and university town like Austin. Regions heavily reliant on industries with high carbon emissions, such as fossil fuel extraction or manufacturing, may experience more pronounced impacts from carbon taxes. These industries would likely face increased costs, potentially leading to shifts in employment and economic activity.

We measure transition risk at the regional level by calculating how much the carbon tax affects the value of the firms operating in each county. To estimate these county-level losses, we weight the industry losses described in the previous sections by the share of each industry's employment in each county (see box "Regional Estimates" for details).[6] This approach does not capture the migration of firms or workers across regions after the implementation of the tax and, by construction, does not consider other policies that local governments can implement to incentivize the shift towards new technologies or mitigate the impact of carbon taxes at the national level. Our approach correctly approximates the first order effects of a national carbon tax if asset value losses are realized immediately and the economy takes some time to adjust (i.e., workers and firms relocate to different industries or regions not affected by carbon taxes, primarily over the long term).

[Insert Box "Regional Estimates" and Figure 1 here]

This is a simplified way of modeling the effects of the carbon tax. We expect that a negative shock to the expected profits of firms with operations in a region will lead to further effects, for example, a decline in employment or a decline in commercial real estate values. Evidence shows that carbon taxes reduce the use of carbon-based energy, but it does not

[6] Of course, the employment composition is not the only determinant of how climate or climate policies will affect a given county or region. Cruz and Rossi-Hansberg (2022) "Local Carbon Policy" argue that the costs of climate change are extremely heterogeneous across locations due to different local temperature effects, differential effects on amenities, productivity, natality, differential costs of migration, and trade across regions.

eliminate its use completely. We abstract from these considerations in this analysis. Nonetheless, the methodology could be extended to evaluate how this tax affects a county's employment, real estate prices, etc.

Figure 2 presents the number of counties according to the market value losses. We find that, across counties, firms lose on average 4.3 percent of their value (the median value is 4.0 percent) but there is significant dispersion with some counties' values dropping by more than 10 percent. To understand where large losses are happening, Table 2 lists the 10 counties with the largest market value losses. The highly impacted counties tend to have large exposures to the highly impacted industries. For example, many of the most affected counties have sizable employment in industries such as gasoline stations (NAICS 447), utilities (NAICS 221), specialty trade contractors (NAICS 238), and food manufacturing (NAICS 311). Even though these estimates consider production linkages most counties in the top 10 are relatively small with all of them below the median level of employment (equal to 6,595).

[Insert Figure 2: Number of counties by Losses due to Carbon Tax here]

[Insert Table 2: Top 10 Counties by market value loss here]

5. How a carbon tax affects community banks in the U.S.

In the U.S., community banks typically operate in one or just a few counties, so the oil patch community bank will be affected in ways that a bank in the state capital won't be.[7] Conversely, a community bank with branches spanning Texas might benefit from enhanced diversification, enabling it to navigate a carbon tax more effectively. Essentially, we anticipate a strong correlation between the regional economic impact of the carbon tax and the performance of smaller banks predominantly rooted in a specific area.

As opposed to a climate stress test we use the geographical footprint of each small bank to capture the effect that the decline in the regional economy will have on that bank's portfolio.

[7] We adopt the designation proposed by the Federal Deposit Insurance Corp's (FDIC's) Community Banking Study (CBS) as of December 2019.

As we describe in what follows, because we want to focus on the assets that are local, we then scale the bank-specific shocks by their loan-to-asset ratio. This exercise is not intended as a climate stress test but as an evaluation of how the shock to the reginal economy might affect different small banks (see box “Climate Stress Tests” for a description of climate stress tests).

[Insert Box “Climate Stress Tests” here]

To capture how a carbon tax affects community banks, we add up the shocks to firm value in the counties in which each bank operates. There is no straightforward way to go from the regional impact to bank value. We use the location of bank branches to identify where each bank operates, and we weight the changes to firm value in each county by the share of the bank’s deposits in each county (see box “Estimating the Effects of Transition Risk on Small Banks”). We use deposits to weight these market value losses at the county level as there is no comprehensive data to capture the regional coverage of the loan portfolio of small banks.[8] As many small banks operate in only one county the link between deposits and regional impact is not as strong as it might sound a priori.

[Insert Box “Estimating the Effects of Transition Risk on Small Banks” here]

Figure 3 presents the count of community banks by market value losses (scaled by the loan to asset ratio and weighted by deposits at the county level). We present losses as a measure of the shock relative to bank-level assets as a normalization. For a $100 carbon tax, the impact on banks portfolio losses accounts for about 2.5 percent of community bank assets. That is, when scaled by the loan to asset ratio the average market value loss in the county where community banks operate account for moderate to small losses.

[Insert Figure 3 here]

[8] We perform a robustness exercise using information on residential mortgage originations and found similar results to those that use deposits.

6. Conclusion

For this article, we conduct an exercise that quantifies the effects of one type of climate transition risk at the industry and regional level. Subsequently, we assess its implications for community banks within the United States.

Initially, an increase in a carbon tax will fall more heavily on high-emission industries, but these industries might transmit some of these costs to final demand via production chains. To estimate the shock to each firm's value, we use an input-output model that considers the linkages across industries and how emissions are transmitted from the source to final demand.

By leveraging these firm value shocks and considering the industry distribution of employment across geographical locations, we estimate the regional (county-level) consequences of a carbon tax. Our findings reveal that the imposition of a $100 tax leads to an average decline in firm value of between 3.5 and 4.5 percent across counties.

The county-level estimates of the shock to firm value allows us to estimate the potential effect of the tax on bank portfolios. We estimate that a $100 carbon tax results in losses to firm value that represent on average 2.5 percent of community bank assets.

Tables and Figures

Table 1: Top 10 Industries by Industry Losses (3-digit NAICS).

NAICS	Description	Emission intensity	% of total emissions	% of total output	Market value losses under $100 tax
324	Petroleum and Coal Products Manufacturing	573	5.2%	1.3%	58.0%
481	Air Transportation	475	2.5%	0.7%	40.1%
221	Utilities	1905	19.4%	1.5%	34.1%
447	Gasoline Stations	40	0.0%	0.0%	24.6%
315	Apparel Manufacturing	137	0.1%	0.2%	24.1%
238	Specialty Trade Contractors	205	4.1%	2.9%	23.1%
486	Pipeline Transportation	1329	0.5%	0.1%	21.8%
311	Food Manufacturing	523	8.4%	2.3%	16.5%
323	Printing and Related Support Activities	59	0.1%	0.3%	12.3%
314	Textile Product Mills	196	0.2%	0.2%	12.1%

Note: Emission intensity corresponds to the ratio of total emissions (in million metric tons of CO2 equivalents) over total industry output (in billion USD). Market value losses correspond to our estimate of losses due to a $100 dollar carbon tax. “% of total emissions” refer to the fraction of total emissions accounted by each industry. “% of total output” refer to the fraction of total output accounted by each industry.

Figure 1: County level impact of a $100 Carbon Tax

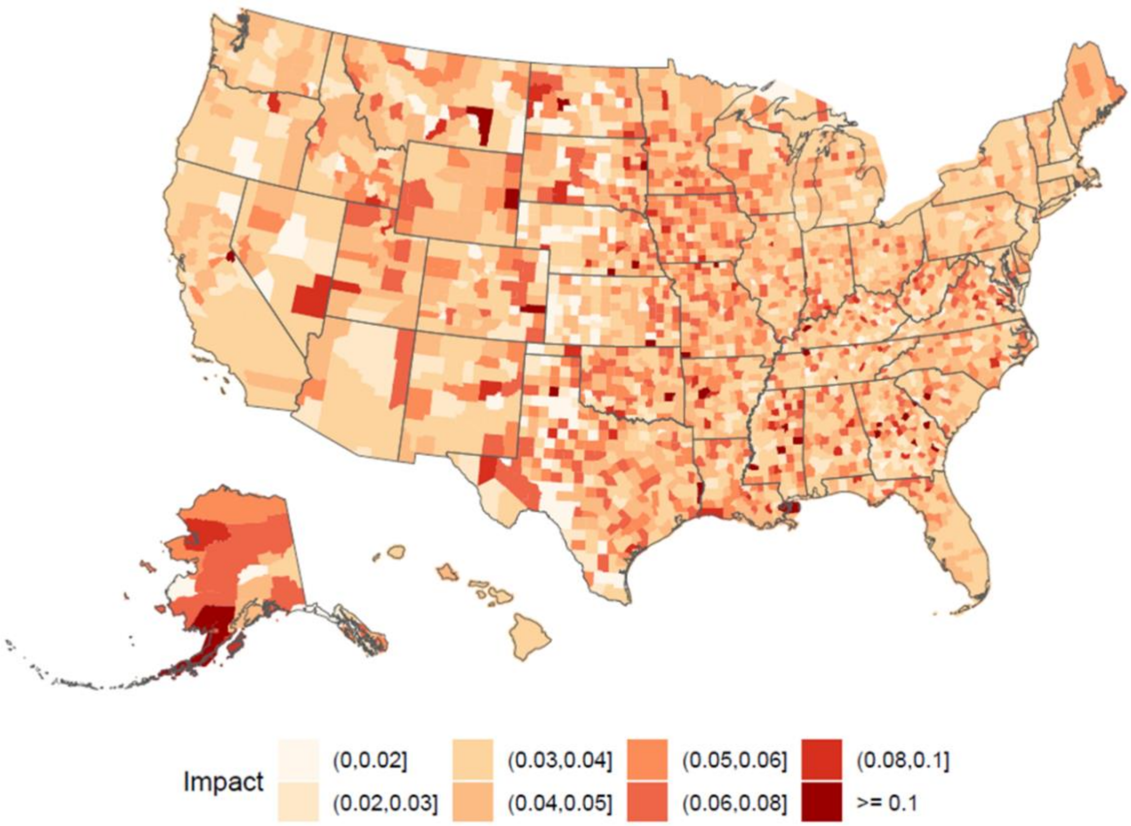


Figure 2: Number of counties by Losses due to a Carbon Tax

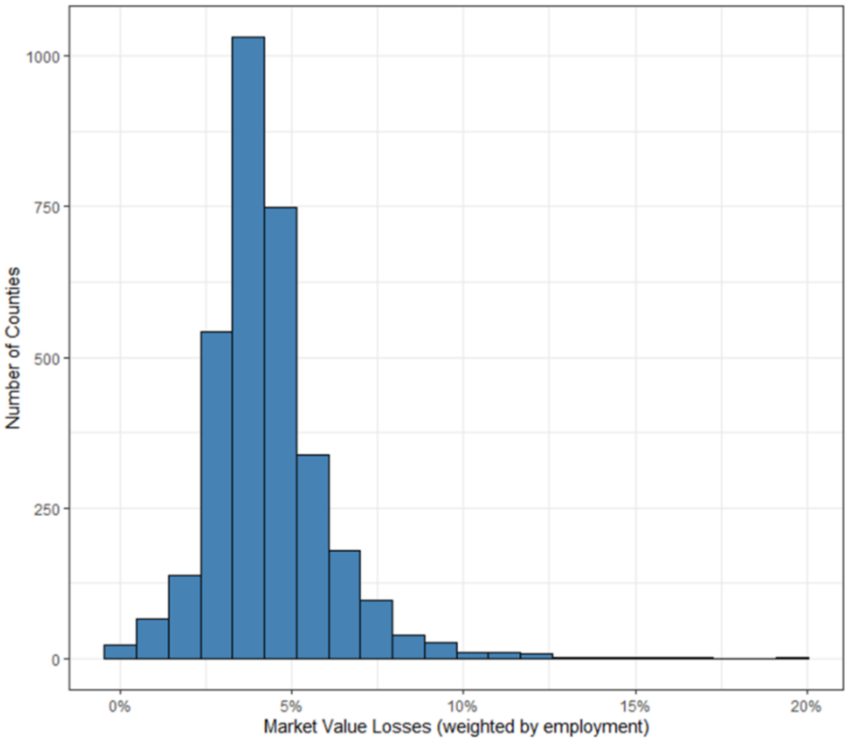
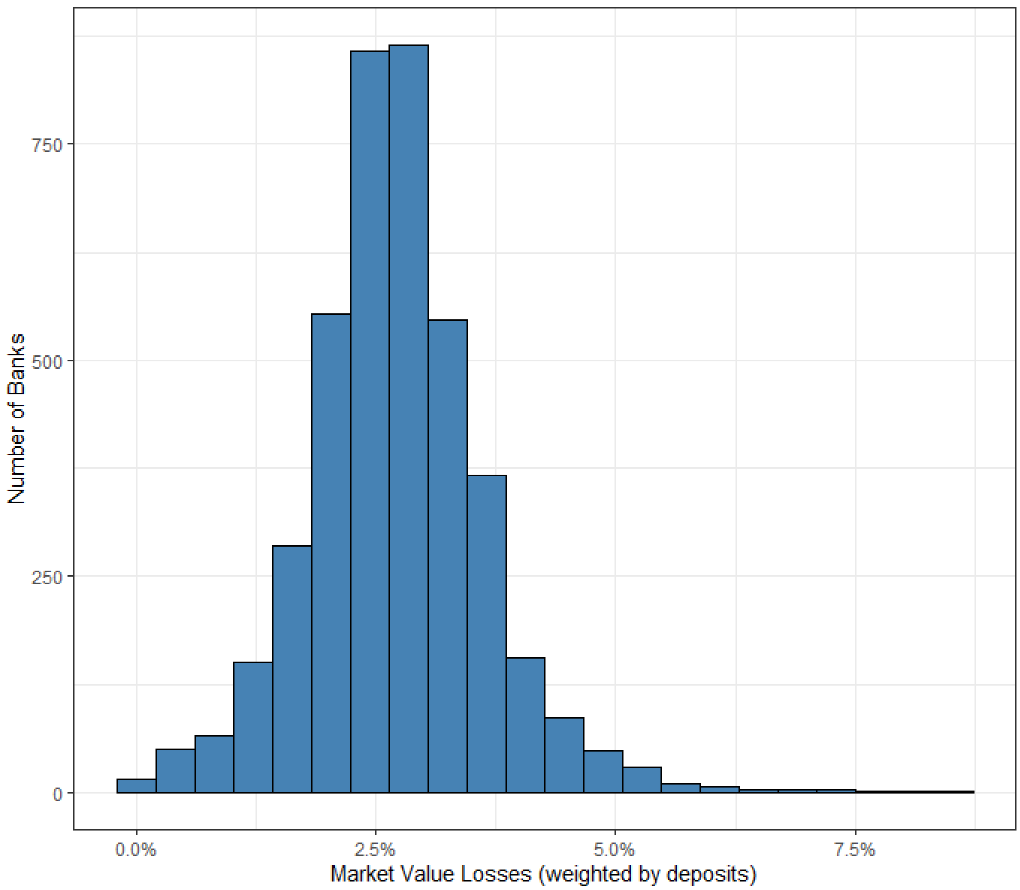


Table 2: Top 10 counties by market value loss

Rank	County	Market value loss under $100 tax	Employment	Top 3 sectors (employment share)
1	Kiowa County, Colorado	19.7%	86	447 (71%), 238 (8%), 491 (8%)
2	Jefferson County, Mississippi	16.8%	297	221 (36%), 621 (26%), 624 (17%)
3	Charles City County, Virginia	16.6%	572	238 (69%), 624 (10%), 111 (9%)
4	Alpine County, California	16.0%	84	221 (42%), 722 (30%), 813 (17%)
5	Manassas Park City, Virginia	14.8%	1812	238 (62%), 423 (11%), 811 (8%)
6	Hancock County, Georgia	14.6%	44	447 (55%), 491 (34%), 441 (11%)
7	Aleutians East Borough, Alaska	14.6%	2219	311 (87%), 921 (7%), 611 (3%)
8	Mercer County, North Dakota	14.4%	3109	221 (32%), 212 (19%), 621 (6%)
9	Kemper County, Mississippi	14.3%	327	221 (28%), 624 (24%), 447 (14%)
10	Rosebud County, Montana	14.0%	1410	221 (26%), 238 (12%), 722 (9%)

Note: For each county the last column provides the three-digit NAICS codes for the top three industries with the largest share of employment in parenthesis. These industries are gasoline stations (447), Utilities (221), Specialty Trade Contractors (238), Food Manufacturing (311), Ambulatory Health Care Services (621), Social Assistance (624), Food Services and Drinking Places (722), Merchant Wholesalers, Durable Goods (423), Postal Service (491), Executive, Legislative, and Other General Government Support (921), Mining (except Oil and Gas) (212), Crop Production (111), Religious, Grantmaking, Civic, Professional, and Similar Organizations (813), Repair and Maintenance (811), (441), Educational Services (611).

Figure 3: Number of small banks by Losses due to a Carbon Tax



BOXES TO BE ADDED TO PAPER

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“Production Model and Emission Estimates”

We use information from EXIOBASE, a multiregional environmentally extended input-output table, to estimate emissions at the industry level in the U.S. at the 3-digit NAICS code level. With data on input-output transactions, labor inputs, energy supply and use, Greenhouse Gas (GHG) emissions, material extraction, land and water use, as well as emissions to air, water, and soil. Exiobase provides a comprehensive up-to-date coverage of the global economy. The GHG footprint of a particular country/product or final demand sector is measured as the total emissions of GHG gases in kilograms of CO2 equivalents (tCO2-eq). It includes GHG, like CO2, CH4, and N20 and calculates their Global Warming Potentials (GWP).[9]

We use the Input-Output table to follow emissions from the source industry along the production chain all the way to the final demand sector to capture the life cycle or ``footprint'' of emissions. This measure of emissions capture emissions associated with the production stage (i.e., they occur in the supply chain and are embodied in inputs from other sectors) and allocate them according to final demand. They also incorporate imports and exports of goods and services so the total of emissions when production linkages are incorporated do not necessarily equal the sum of emissions at the source. In some sense, when using the level of emission distributed to the final demand sector to capture the link between carbon taxes and the industries, we assume that input suppliers along the production chain increase their price by the full amount of the tax. In this case, sectors that are heavy users of inputs with high emissions intensity bear relatively large share of the tax.

[9] The GWP was developed to allow comparisons of the global warming impacts of different gases. CO2, by definition, has a GWP of 1 regardless of the period used, because it is the gas being used as the reference. Methane (CH4) is estimated to have a GWP of 28–36 over 100 years. As most of the literature, we’ll focus on CO2 equivalent emissions using GWP 100.

A recent literature has developed general equilibrium models with a particular attention to sectoral heterogeneity and understanding how shocks propagate through production chains. These models are important for understanding the amplification and propagation of shocks via input-output connections while taking seriously sectoral elasticities of substitution of intermediate inputs.[10] Our framework (via the emission estimates) captures input-output linkages, but it is not as flexible as these models where it is possible to evaluate arbitrary elasticities of substitution and returns to scale.

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[10] Some important examples in this literature include Horvath (2000) "Sectoral Shocks and Aggregate Fluctuations", Atalay (2017) "How Important are Sectoral Shocks?", Baqaee and Farhi (2020) "Productivity and Misallocation in General Equilibrium," Miranda Pinto and Young (2022) "Flexibility and Frictions in Multisector Models." See Devulder and Lisack (2020) "Carbon tax in a Production Network: Propagation and Sectoral Incidence" for an example of transition risk.

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“Regional Estimates”

To estimate the regional impact of the carbon tax, we use the distribution of employment across counties at the 3-digit NAICS level provided by the Bureau of Labor Statistics (BLS). With the industry level value losses at hand, we proxy the exposure of any county to each industry by the fraction of employees that work for that industry. Then, we estimate the county-level exposure to the carbon tax by combining the county’s industrial exposure with our estimates for industry-level value losses.

Figure 1 display the geographical dispersion of our estimated losses. As we consider linkages across industries, we find that losses are broad in terms of geographical coverage as about 91 percent of counties would experience larger than a 2 percent market value loss. About 25 percent of those counties would experience larger than a 5 percent loss.

[Insert Figure 1 here]

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"Climate Stress Tests"

The exercise we perform is not intended as a climate stress test. However, there is a growing literature and interest of central banks in analyzing the link between financial stability and climate change.

Climate stress tests that evaluate transition risk have some important differences but are similar in spirit to standard stress tests (i.e., those with a primary focus on capital and liquidity levels during scenarios of stress) performed by macroprudential supervisors.

Standard stress tests are generally conducted for a 2 to 3 years horizon, the evaluate an extreme stress scenario, and use detailed loan level information. Banks must meet capital and liquidity requirements under stress conditions. They also play an informational role for the bank management about risks.

Climate transition risk stress tests focus on much longer horizon (10 years) and the scenarios often begin with a projection of future emissions. A common example for these climate scenarios is the scenarios provided by the Network for Greening the Financial System (NGFS) that range from "Current Policies" to "Net Zero 2050" (which is the most ambitious scenario that limits global warming to 1.5C through stringent climate policies and reaches net zero CO_2 emissions around 2050).

As the primary goal of these exercises is to quantify the risks to financial institutions with different mixes of industry exposures, the next step is to link the aggregate outcomes to sectoral or regional effects. One approach expands the macroeconomic model to incorporate an input-output structure that can provide sectoral effects. [11] The alternative approach which goes directly from the increase in carbon taxes to asset value or credit risk evaluates the impact

[11] See Vermeulen, Schets, Lohuis, Kolbl, and Jansen (2019) "The Heat is on: A framework measuring financial stress under disruptive energy transition scenarios" and ACPR (2021) "A First assessment of financial risks stemming from Climate Change: The main results of the 2020 climate pilot exercise."

of these policies to each industry or region using a financial model.[12] A key input into constructing these links is the estimates of carbon emissions at the industry level.

The final step in evaluating how transition risk affects financial institutions is to establish a link between the industry or reginal effects to the portfolio of these institutions. A direct approach can be used if loan level data with industry information is available. If this type of data is not available, one needs to infer the loan composition and the exposure of the loan portfolio to industry or regional losses.

At this stage, most central banks climate stress tests have been informational and not actually designed to affect bank capital requirements.

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[12] Reinders,Schoenmaker, and Van Dijk (2020) "A finance approach to climate stress testing," and Grippa and Mann (2020) "Climate-Related Stress Testing: Transition Risks in Norway" estimate the value added for each industrial sector and assign a tax on carbon emissions.

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"Estimating the Effects of Transition Risk on Small Banks"

To proxy for a bank's lending footprint, we use a bank's branch deposits obtained from the FDIC's Summary of Deposits as of June 2019. The FDIC's Summary of Deposits is the annual survey of branch office deposits as of June 30 for all FDIC-insured institutions, including insured U.S. branches of foreign banks. All institutions with branch offices are required to submit the survey; institutions with only a main office are exempt.

Given our estimates for county-level transition risks, we calculate bank-level estimate of the transition risks within its lending footprint. That is, for any given bank, we take the average of county level losses across the counties where the bank operates and weight each county by the size of the deposit base of the bank in that county.

Once we have these bank level estimates of market value losses, to quantify the potential impacts on a community bank's operation, we multiply a bank-level estimate for the transition risks by a bank's loans, which then is scaled by total assets.

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