The global impact of national environmental commitments

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Abstract
There is a global push for nations to improve domestic environmental outcomes through policy change. Many of these policy initiatives are likely to result in reductions in domestic production in favour of imported goods and services. This has the potential to dramatically increase environmental impacts outside of the country implementing policy change and change where the environmental impacts of production are felt. Yet, little is known about how the displacement of environmental impacts from domestic policies to achieve environmental outcomes are felt globally. Here we assess how a policy aimed at reducing domestic production for every country propagates through the trade network to drive environmental impacts elsewhere. We identify the variation on impacts among countries and where these impacts may occur. We then identify how the structure of the trade network may explain potential impacts and what this means for policy development to meet global environmental targets. This has implications for coordination of environmental policies to achieve equitable environment outcomes.

Introduction

Over the last few decades, there has been an increasing push for governments around the world to address environmental issues such as climate change through domestic policy change (Bastin et al., 2019; Grassi et al., 2017; Mackey et al., 2020). Domestic environmental and conservation policies such as emissions reductions targets and afforestation plans for carbon sequestration play an important role in promoting sustainability and combatting such issues (Canadell & Raupach, 2008; Lewis et al., 2019; Phelps et al., 2012). Afforestation policies are of particular interest, as they may result in productive agricultural land being repurposed to grow trees to sequester carbon, thus increasing competition for land. When countries enact such domestic policies, they may no longer domestically produce particular agricultural commodities, and the demand for these commodities will be met through trade with other countries (Hornborg, 2009; Meyfroidt, 2018; Meyfroidt et al., 2013). However, the global economy is a highly telecoupled system, meaning that distant regions can be interconnected bi-directionally through trade or non-market factors (Liu et al., 2013), and global supply chains and such domestic afforestation policies may have unintended environmental consequences elsewhere (Aichele & Felbermayr, 2015; Change, 2009; Ferreira et al., 2018; Lewison et al., 2019). Often this can be at the expense of countries that have less stringent governance surrounding environmental policy, also known as offshoring (Baylis et al., 2021; Lewison et al., 2019). Yet, we currently have few insights about how the global environmental consequences of domestic afforestation policies may vary from country to country. Better understanding of this is critical for coordinating global responses to climate change and environmental degradation.

Domestic afforestation policies require cooperation at global scale in order to achieve the true goals of such policies, and as such it is important that we understand how changes in domestic land availability and price as a result of such policies may be driving leakage of environmental impacts elsewhere (Lewison et al., 2019). For example, the UK afforestation policy, which is meant to help the UK achieve a net-zero emissions plan, places restrictions on the amount of land that can be used for agriculture and would require some of this land to be used for tree planting and agroforestry (Westaway et al., 2023). The Climate Change Committee (2020) estimates that by 2050 approximately 21% of agricultural land in the UK will need to be converted to such activities. Similar patterns are also seen with the Natural Forest Conservation Program (NFCP) in China, which aimed to convert 6 million ha of marginal farmland to forests (Zhang et al., 2000) and Chile's Decree Law 701, which provides afforestation subsidies and led to changes in agricultural land-use (Heilmayr et al., 2020). Furthermore, afforestation policies in places such as Vietnam, Russia and India have resulted in increases in forest extraction in other countries, or leakage (Meyfroidt & Lambin, 2009; Meyfroidt et al., 2010; Pendrill et al., 2019).

Globally, afforestation and forest conservation policies have resulted in increased deforestation in other areas (Gan & McCarl, 2007; Oliveira et al., 2007). Although leakage has been understood conceptually and identified in many sectors (Alix-Garcia et al., 2012; Aukland et al., 2003; Friis et al., 2016; Gellert et al., 2017), there is still a need to quantify how afforestation policies and changes in domestic production can shape environmental outcomes elsewhere (Grassi et al., 2017; Mehling et al., 2018; Meyfroidt et al., 2013). Large-scale afforestation efforts often require conversion of agricultural land that is needed to provide other land-based services such as food production, often leading to increased competition for domestic land and land prices (Doelman et al., 2020; Frank et al., 2017; Kreidenweis et al., 2016; Van Meijl et al., 2018). Furthermore, under various future climate scenarios, demand for agricultural commodities will increase and create further competition for available land (Eitelberg et al., 2016; Power, 2010; von Jeetze et al., 2023). This means that alternative sources of food production, or an increase in efficiency of domestic agricultural production, will be needed to meet demand, with countries often choosing to increase their reliance on imports to satisfy domestic demand (Huang et al., 2019; Pastor et al., 2019). Balancing the need for food with the need to mitigate climate impacts with afforestation policies is difficult and can result in leakage from one country into another (Frank et al., 2017; Hasegawa et al., 2015; Iyer et al., 2015; Van Meijl et al., 2018). As domestic afforestation policies are enacted in order to combat climate change, and the demand for agricultural products is expected to increase, it is important to identify and understand how such policies may create environmental leakage elsewhere.

Current research highlights the gaps that exist in understanding the patterns of trade that exist with agricultural and food production commodities, which are particularly relevant to our work due to the mechanisms by which afforestation policies reduce the amount of agricultural land available for production (Halpern et al., 2022). Furthermore, it is also necessary to identify who is receiving the impacts of these changes that arise from domestic afforestation policies (Halpern et al., 2022). Using a computable general equilibrium (CGE) model (GTAP) (Corong et al., 2017; Hertel, 1997), we will identify how changes in the expected effect of land-use changes land prices as a result of domestic afforestation policies could generate environmental leakage in other countries. We will primarily focus on agricultural commodities and their environmental impacts such as disturbance, excess nutrients from nitrogen and phosphorous use, blue freshwater use and greenhouse gas (GHG) emissions (Halpern et al., 2022).

As afforestation policies are meant to help reduce total greenhouse gas emissions, it is important to understand the impacts they may be leaking to other countries as a result of the loss of agricultural land. For the first time we generate insights into the countries that may be most vulnerable to the telecoupled impacts of domestic climate policies and which countries are most prone to the export of their environmental impacts. In doing so we aim to answer the following research question: What are the likely displaced environmental impacts of domestic emissions reductions policies, which countries have the largest impacts, and which countries are most vulnerable to these impacts?

Approach

(1) increase the price of land as an input to agricultural production by implementing a shock in GTAP one country at a time. This can be done using the following GTAP inputs:
Variable to Shock: qe, supply of mobile and sluggish endowment e in region r
Elements to Shock: Land, REG
% Change Shock: -5
Shock qe("Land",REG) = uniform -5

(2) implement this shock for all 141 countries in GTAP and create a 141 x 141 matrix of countries and the results of their domestic afforestation policy shocks. The 141 x 141 matrix will present results in terms of GDP and regional welfare measured by equivalent variation, as it accounts for the value to final consumers rather than just the market transaction value of economic production (Johnson et al., 2023). This matrix will show which countries are vulnerable to the economic impacts of trade due to domestic afforestation policies.

(3) We can then use the GTAP results in terms of changes in the volume of supply of a commodity in the GTAP region (country) being shocked at initial base price, represented by DQC and provided by the .vol file obtained from our original experiment run for each country. DQC data for each commodity we shock can then be mapped to the economic allocation of the same commodities in the Agri-Footprint 6 database in order to calculate environmental impacts for four environmental impact categories listed below. The economic allocation of the Agri-footprint 6 database uses the price of commodities to compute the value streams of the commodities. This will allow us to calculate various environmental impacts with indicators provided by the Agri-footprint 6 database.

(4) Environmental impacts will consist of four categories of impact we obtain from the Agri-footprint 6 database and that can be linked using the results from the changes in DQC of each commodity in each country in GTAP. The four impact categories are land-use, water consumption, marine/freshwater eutrophication and global warming contributions. These are measured from sources occurring within the farm gate, and activities that occur outside of this such as transportation and processing will be excluded because mapping these activities to a location is difficult (Halpern et al., 2022).

(5) Once commodities have been analysed, we can identify countries that will receive the brunt of environmental impacts using our results from (4) to show which countries will have the largest changes in the four environmental indicators we mention above.

Methods

GTAP

In order to assess the change in trade flows as a result of changes in domestic policy, our experiment utilises the GTAP computable general equilibrium (CGE) model, which combine economic theory with real economic data in order to derive computationally the impacts of policies or shocks in the economy. GTAP combines a validated general equilibrium theoretical model with a curated database of global trade, financial and input/output relationships (Beckman et al., 2011; Valenzuela et al., 2005). The GTAP model consists of 341 market regions, 17 sectors and 22 inputs (Corong et al., 2017), and GTAP data for our experiment comes from GTAP 11 database (Aguiar et al., 2022). GTAP results will be presented in terms of regional welfare measured by equivalent variation (Hausman, 1981), as this is better than GDP because it accounts for the value to final consumers rather than just the market transaction value of economic production (Johnson et al., 2023).

As leakage from afforestation policies can be the result of changes in the cost of domestic production (Lewison et al., 2019), an economic shock is needed that represents a decrease in the amount of land that is available for production. We simulate the outcome of domestic afforestation policies that aim to switch land uses to forest to curb domestic new emissions by incorporating price shocks on land as an input to production. In order to change the cost of domestic production, we increase the price of land using a shock in GTAP. As we are focusing on agricultural commodities, we will shock the price of agricultural land as an input to production in GTAP, implicitly assuming that afforestation only affects agricultural land.

In GTAP this shock can be defined as the following:
Variable to Shock: qe, supply of mobile and sluggish endowment e in region r
Elements to Shock: Land, REG
% Change Shock: -5
Shock qe(“Land”,REG) = uniform -5

This shock best represents the policies we are trying to simulate as it will result in changes in the amount of land that is available for production, specifically a 5% reduction in available land in the country we are shocking, similar to what happens when afforestation or similar policies are implemented as they result in less land being available for production. This shock will be implemented and ran as an experiment for each country, showing how a domestic afforestation policy in one country results in impacts on the 140 other regions in GTAP. This will be conducted for all 141 regions in GTAP in order to create a 141 x 141 vulnerability matrix using regional welfare measured by equivalent variation, where we can highlight which countries are vulnerable to leakage as a result of changes in domestic afforestation plans.

Environmental Indicators
Once we obtained the changes in GDP and regional welfare measured by equivalent variation after shocking each region in GTAP, we then need data on the environmental impacts (externality) due to changes in production of each commodity in each country (e.g., CO_2, water, biodiversity, etc.), noting that this may be positive or negative. This is possible using the Agri-Footprint 6 database. The Agri-footprint 6 database is a thorough and consistent life cycle inventory (LCI) database covering data on food, feed, and agricultural intermediate products (Blonk Sustainability, 2023). The Agri-footprint 6 database contains the production, processing, and transport of many commodities at the global level and would allow us to report on the effects of production change as a result of the changes in the price of land. Products in the database are allocated three separate ways (economic, mass or energy) and we would use the economic allocation to map to our GTAP results as our GTAP results will be presented in terms of GDP and regional welfare by equivalent variation. We focus on agricultural commodities as strategies for reforestation will most likely affect agricultural land, and hence agricultural commodities are most relevant (Doelman et al., 2020; Kreidenweis et al., 2016). Furthermore, within this database there are many commodities that cannot map to GTAP or that do not have enough data for all of the regions in our analysis. Therefore, focusing on agricultural commodities also allows us to map the Agri-footprint data more easily to our GTAP results. The following commodities in the Agri-Footprint database can be mapped to GTAP sectors and have data for at least 10 regions globally:

- Oat, Rye, Soy, Maize, Sugar Beet, Sunflower seeds, Wheat, Rapeseed, Potatoes, Peas, Linseed, Barley, Livestock

Possible Results/Figures
Figure: 141 x 141 heatmap ranked by income groups
Possible clustering of commodities (Matrix for each commodity)?
Output: Matrix where extreme events may be most damaging.

Discussion
- We are thinking of domestic environmental policies (e.g., UK afforestation, China Grain to Green) that may increase the need for imports to meet domestic demand for commodities.

- The countries that have the worst impact would be the ones that would have the best outcomes environmentally if they changed their policy.

- Changes in demand at the importing country will change direct imports from countries but may also change imports and exports among non-related countries through second-order effects.
- Taking a network approach to explain impacts and/or vulnerability based on their place in the network and where the impacts come from.
- Changes in demand at the importing country will change direct imports from countries but may also change imports and exports among non-related countries through second-order effects, which will be accounted for in GTAP.
- How can we improve policy so that we are not displacing impacts?
- What are the most commonly occurring mechanisms and patterns that have emerged from our research? (i.e. are developed countries mostly exporting their impacts to developing countries? Or are there other patterns that emerge?)
- What explains the relationships between countries with less impacts and those with more? I can hypothesise that developed countries will have the largest displaced impacts, and that European countries in general may have large environmental impacts due to constraints on the space available to them.

Conclusion

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