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Market Structure and the Environmental Implications of Trade Liberalization: Russia's Accession to the World Trade Organization

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Abstract

We investigate the environmental impacts of Russia's World Trade Organization (WTO) accession with a computable general equilibrium model incorporating imperfectly competitive firms, foreign direct investment and endogenous productivity. WTO accession increases CO_2 emissions through technique (–), composition (+) and scale (+) effects. We consider three complementary policies to limit CO_2 emissions: cap and trade, emission intensity standards and energy efficiency standards. With imperfectly competitive firms, gains from WTO accession result with any of these policies. If we assume perfectly competitive market structures, the negative environmental impacts of WTO accession are smaller and no net gains arise when environmental regulation involves energy intensity or efficiency standards.

1. Introduction

General equilibrium considerations can have first order importance in the evaluation of trade or environmental policies. Thus, computable general equilibrium (CGE) models are widely used to quantify the prospective economic and environmental impacts of policy regulations such as trade reforms or emission control policies. The bulk of CGE assessments, however, is based on models that employ constant-returns-to-scale (CRTS) and perfectly competitive markets.[1] Of the 54 CGE assessments of climate change policy surveyed by Carbone and Rivers (2014), only Babiker (2005) and Böhringer et al. (2008) incorporated imperfect competition.[2] As a result, nearly all assessments omit potentially important impacts of increasing returns to scale (IRTS), where endogenous productivity effects can significantly alter the results.

The integrated trade and environment model applied here contains the features of Krugman (1980) and Ethier (1982) by incorporating increasing returns to scale, monopolistic competition and endogenous productivity effects from additional varieties of goods in imperfectly competitive sectors. Crucially, however, our model also incorporates foreign direct investment (FDI) in business services with endogenous productivity effects from additional varieties of business services. We thereby reflect the theoretical analysis of Markusen (1989), Francois (1990) and Markusen et al. (2005) in which the greater availability of business services results in total factor

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productivity gains to the manufacturing sector. Remarkably, the theoretical literature is supported by a growing body of empirical literature, including several studies using firm-level data, which has found a significant positive impact on total factor productivity from additional FDI in business services.[3]

To our best knowledge, our model is the first CGE model designed for trade and environmental policy analysis to incorporate these features. We use this model for the impact assessment of Russia's accession to the World Trade Organization (WTO). After 18 years of negotiations, Russia joined the World Trade Organization in 2012. Russia's accession agreement calls for wide-ranging reforms that will be implemented in phases through to 2020.[4] Given that the Government of the Russian Federation's Program on Environmental Protection 2012–2020 emphasizes the need for environmental policies to accompany economic growth to achieve sustainable development,[5] policy makers in Russia are concerned about the environmental effects of WTO accession, and may wish to implement regulation in order to mitigate potentially negative implications for the environment.

In their impact analysis of the North American Free Trade Agreement (NAFTA) for Mexico, Grossman and Krueger (1993) provide evidence on the endogeneity of trade liberalization and environmental policy in that trade liberalization induced greater environmental regulation. Their observation is given substantial support by the econometric analysis of Antweiler et al. (2001) who examine sulphur dioxide emissions in more than 40 countries following trade liberalization. They find that there is a decrease in emissions following trade liberalization, largely because of stricter environmental regulation.

Acknowledging the endogeneity of environmental policy with trade liberalization, and the stated objective of the Russian government to reduce CO_2 emissions (see section 2), our analysis goes beyond an isolated impact assessment of Russia's WTO accession. More specifically, we combine the policy changes of WTO accession with three alternate environmental regulations designed to reduce CO_2 emissions: market-based cap and trade; emission intensity standards; and energy efficiency standards. We also separately estimate the impacts of these three emission abatement policies independent of WTO accession. Our simulations should help authorities to design policies that minimize the economy-wide costs of achieving a given level of emission reduction, and thereby address political resistance to environmental regulation.

One of our key results is that, in the simulations combining WTO accession with the two less efficient emission abatement policies of setting standards (rather than adopting cap and trade), the sign of the impact on the net welfare effects depends on the underlying market structure. Contrary to the results in an IRTS setting with imperfect competition, WTO accession does not generate sufficient gains in the CRTS setting with perfect competition to provide net benefits when the costs of the less efficient emission abatement policies are incorporated. While our results are consistent with earlier studies that suggest increased pollution with IRTS models (absent offsetting environmental regulations), our analysis indicates that there are greater gains available when taking IRTS into account, which allow for net gains after regulation to produce a net cleaner environment.

The remainder of the paper is organized as follows. In section 2 we summarize the environmental policy debate in Russia, which explains the interest of Russian policy makers in potential trade-offs between trade liberalization and environmental quality. In section 3 we present the CGE model and the data sources underlying our impact assessment of Russia's WTO accession. In section 4 we motivate the policy scenarios to be investigated and discuss simulation results from the IRTS model with imperfect competition. In section 5 we provide a comparison with the results obtained from the CRTS model with perfect competition. In section 6 we assess the sensitivity of our results to key parameter assumptions. In section 7 we conclude.

2. Environmental Policy Debate in Russia

Russia is the largest country in the world spanning nine time zones with a population of more than 140 million people. It is also one of the richest countries in the world for oil, gas and a wide range of minerals. Russia's natural endowment has been a key driver of economic growth in the current millennium, based on production and export of raw materials. As a legacy of the Soviet period, many industries are characterized by high resource use, very high energy intensities and obsolete production processes. The quality of environmental conditions in Russia is inadequate in about 15% of the country's territory, which is home to 57% of the population.[6] Because of high levels of air pollution, the estimated average life expectancy of the population is reduced by about one year, while in more polluted cities by about four years. It is estimated that this factor is the reason for about 8% of deaths annually. The main sources of air pollution are particulate matter, sulphur dioxide and nitrogen oxide linked primarily to fossil fuel combustion (International Finance Corporation (IFC), 2008).

Russia is currently the world's fourth-largest emitter of greenhouse gas emissions. While Russia ratified the Kyoto Protocol in 2004,[7] it has refused so far to commit to internationally binding post-Kyoto commitments. Nonetheless, Russia is still pursuing a national greenhouse gas emission reduction program of between 15% and 25% from 1990 emission levels by 2020 as well as a broader set of policies for sustainable development.[8] Along with emission reduction targets, the Russian government emphasizes the need for increased investments in energy and resource efficiency,[9] cleaner technologies, recycling and reuse of wastes. Against this background, Russia's WTO accession has engendered concerns about potentially negative environmental impacts.

3. CGE Model for Russia: Structure and Data

For the economic and environmental impact assessment of Russia's WTO accession we extend a 10-region, 30-sector computable general equilibrium model of the Russian economy (Rutherford and Tarr, 2010) by incorporating emissions data and by allowing inter-fuel substitution in production and consumption activities. Below, we provide a non-technical model summary[10] and describe the data sources for model parameterization.

Model Structure

Sectors, regions, and primary factors of production There are 30 sectors in the model that are listed in Table 1. We group several contiguous regions of Russia into 10 "regional markets" listed in Table 3.[11] There are three types of sectors: perfectly competitive goods and services, imperfectly competitive goods and imperfectly competitive business services (with FDI). We assume that firms operate at the regional market level.

Primary factors include skilled and unskilled labor and three types of capital: mobile capital (within regions); sector-specific capital in the energy sectors reflecting

Table 1. *Sectoral Emission Intensities*

	CO_2 intensity			Emission intensity of non-CO_2 pollutants					
	Total	*Direct*	*Indirect (from electricity)*	*Sulphur dioxide*	*Hydrocarbons*	*Carbon monoxide*	*Nitrogen oxide*	*Particulate matter*	*Volatile organic components*
Imperfectly competitive goods									
Nonferrous metals (NFM)	0.6	0.3	0.3	4.3	0.0	1.4	0.2	0.5	0.0
Ferrous metals (FME)	3.5	3.1	0.4	1.9	0.0	1.1	0.1	0.3	0.0
Chemicals (CHM)	2.7	2.0	0.7	0.2	0.1	0.5	0.2	0.3	0.2
Food industry (FOO)	0.5	0.4	0.1	0.0	0.0	0.1	0.0	0.1	0.0
Metal working (MWO)	1.0	0.8	0.3	0.0	0.0	0.2	0.1	0.2	0.0
Timber, wood and paper (TPP)	1.3	0.9	0.3	0.0	0.0	0.1	0.0	0.1	0.0
Other industries (OTI)	1.0	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Construction materials (CNM)	3.1	2.5	0.5	0.1	0.0	0.6	0.3	1.0	0.0
Perfectly competitive goods and services									
Electricity (ELE)	7.9	7.2	0.7	2.8	0.0	0.4	1.8	2.3	0.0
Oil refining (OIL)	0.5	0.3	0.2	0.3	0.1	0.2	0.1	0.1	0.3
Crude oil (CRU)	0.5	0.3	0.2	0.2	1.4	3.8	0.2	0.7	1.2
Textiles and apparel (CLI)	0.6	0.3	0.3	0.1	0.0	0.2	0.1	0.2	0.0
Housing (HOU)	3.7	2.9	0.8	0.1	0.0	0.1	0.0	0.0	0.0
Coal (COL)	5.7	5.4	0.2	0.1	3.7	0.1	0.1	0.3	0.0
Gas (GAS)	5.7	5.6	0.2	0.0	0.2	0.3	0.0	0.0	0.1
Agriculture and forestry (AGR)	0.5	0.4	0.1	0.0	0.0	0.1	0.0	0.1	0.0
Other goods sectors (OTH)	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Public services, culture (HEA)	0.9	0.5	0.4	x*	x*	x*	x*	x*	x*
Construction (CON)	0.5	0.5	0.1	x*	x*	x*	x*	x*	x*
Post (PST)	0.2	0.1	0.1	x*	x*	x*	x*	x*	x*
Trade, wholesale and retail (TRD)	0.2	0.2	0.0	x*	x*	x*	x*	x*	x*
Imperfectly competitive business services with FDI									
Maritime transportation (MAR)	0.6	0.6	0.1	0.1	1.5	0.3	0.2	0.2	0.1
Railway transportation (RLW)	0.9	0.4	0.4	0.1	1.3	0.3	0.1	0.2	0.1
Truck transportation (TRK)	1.3	1.2	0.1	0.1	1.2	0.3	0.1	0.2	0.1
Air transportation (AIR)	1.6	1.5	0.1	0.1	1.1	0.2	0.1	0.2	0.1
Other transportation (TRO)	0.9	0.5	0.3	0.1	1.2	0.3	0.1	0.2	0.1
Pipleline transportation (PIP)	7.0	6.3	0.7	0.1	1.5	0.3	0.2	0.2	0.1
Telecommunications (TMS)	0.2	0.1	0.1	x*	x*	x*	x*	x*	x*
Science and engineering (SCI)	0.7	0.5	0.1	x*	x*	x*	x*	x*	x*
Financial services (FIN)	0.9	0.7	0.2	x*	x*	x*	x*	x*	x*
Emission averages									
Final consumption	0.2	0.1	0.1						
Sector average	1.3	1.0	0.2	0.3	0.2	0.3	0.1	0.2	0.1
Average including final consumption	1.0	0.8	0.2						

Notes: CO_2 emission intensity: kilograms per ruble; non-CO_2 emissions intensity: grams per ruble. *Non-CO_2 pollution data are unavailable for these sectors.
Sources: SUST-RUS database, described in SUST-RUS (2012a–c) and Böhringer et al. (2014, Appendix A); Rosgidromet (2013, Table A3.3); Ministry of Natural Resources and the Environment of the Russian Federation (2007); and Rosstat online database at: http://www.gks.ru.

the exhaustible resource; and sector-specific capital in imperfectly competitive sectors. We also have primary inputs imported by multinational service providers, reflecting specialized management expertise or technology of the firm. The existence of sector-specific capital in several sectors implies that there are decreasing returns to scale in the use of the mobile factors and supply curves in these sectors slope up. Labor is assumed immobile across regions.

As to factor earnings, the representative agent in the region obtains the returns from skilled and unskilled labor employed in the respective region. We assume that half of all the capital in any region is held by the representative agent in the region and the other half by a national mutual fund. The national mutual fund invests in all regions and obtains an overall return. The representative agent in the region also holds shares in the national mutual fund.[12]

For each region we report returns to capital as returns to the three types of regional capital held by the region's representative agent. In addition, the region's representative agent obtains a share of the returns from the national mutual fund. The region's return from national capital is the region's share of the return of the national mutual fund reported as a percentage of initial consumption of the region.

Non-fossil fuel sectors In Figure 1, we depict the structure of production for non-fossil fuel sectors where substitution possibilities on the input side are captured by constant elasticities of substitution (CES) and transformation possibilities on the ouput side are prescribed by constant elasticities of transformation (CET).[13] Regional firms use intermediate inputs (which can be foreign inputs, inputs from other regions of Russia or from their own region) and primary factors of production to produce output. We emphasize that business services are not part of the "composite of other goods and services"; rather business services substitute for primary factors of production.[14] This structure allows the model to capture the econometric evidence, cited above, that greater access to business services increases productivity in the firms that use business services. We show in our sensitivity analysis that the elasticity of substitution between business services and primary factors of production significantly impacts the results. We generalize Rutherford and Tarr (2010) by allowing for inter-fuel substitution, which is central to the analysis of greenhouse gas emissions, in particular CO_2 emissions from the combustion of fossil fuels.

Perfectly competitive goods and services Firms in each regional market have three choices for sales: sell in their own regional market, sell to other parts of Russia, or export to the rest of the world. Firms maximize revenue for any given output level based on their transformation possibilities between goods for the three markets. For all firms within the same regional market, the product they export to all other regional markets of Russia is homogeneous. It follows that for each competitive good, there will be only three prices: the price of good *g* in regional market *r*, the price of good *g* from regional market *r* in all other parts of Russia and the price of good *g* from regional market *r* in the rest of the world.

Economic agents in a representative regional market *r* employ multi-stage budgeting based on nested CES expenditure functions. They optimize expenditures on foreign goods vs goods from Russia, then between goods from other Russian regional markets and their own regional market, and also between goods from the other Russian regional markets. This structure assumes that consumers differentiate the

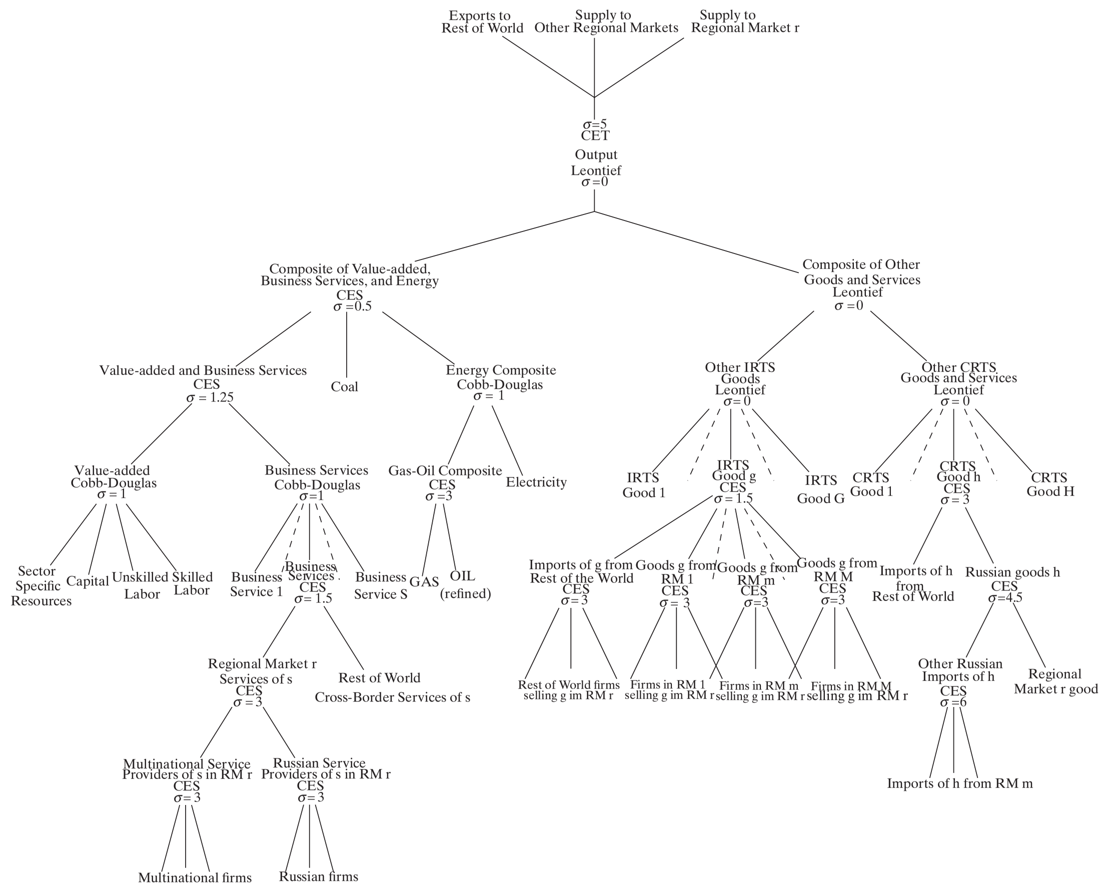

Figure 1. Production Structure for non-Fossil Fuel Sectors

Notes: (a) For business services, there is only supply to the home regional market and to the rest of the world. (b) We take $\sigma = esub = 3$, except based on Ivanova (2005), we take $\sigma = 3.1$ in MWO; $\sigma = 2.6$ in TPP; $\sigma = 2.5$ in CNM; and $\sigma = 1.8$ in OTI.

products of producers from different regional markets; but, they regard as homogeneous the products of different producers from the same regional market.

Imperfectly competitive goods Economic agents in each regional market optimally allocate expenditures among the goods available from the different regional markets of Russia and the rest of the world producers. Since we assume identical elasticity of substitution at all levels, this is equivalent to firm-level product differentiation of demand. That is, the structure is equivalent to a single stage in which agents decide how much to spend on the output of each firm.

We assume that imperfectly competitive manufactured goods may be produced in each region or imported. Both Russian and foreign firms in these imperfectly competitive industries set prices such that marginal cost (which is constant with respect to output) equals marginal revenue in each regional market. There is a fixed cost of operating in each region and there is free entry, which drives profits to zero for each firm on its sales in each regional market in which it sells: quasi-rents just cover fixed costs in each region in the zero-profit equilibrium. We assume that all firms that produce from the same regional market have the same cost structure, but costs differs across regions.

Foreigners produce the goods abroad at constant marginal cost but incur a fixed cost of operating in each regional market in Russia. Becuase of free entry, in equilibrium the import price (less tariffs) must cover fixed and marginal costs that foreign firms incur in each regional market.

Similar to foreign firms, Russian firms also produce their goods in their home regions; they incur a fixed cost of operation in each regional market in which they operate. Owing to free entry, there are zero pure profits and the product price must just cover both fixed and marginal costs of operation in that regional market.

We assume that Russian firms do not have any market power on world markets and thus act as price takers on their exports to world markets. On exports to the rest of the world, price thus equals marginal costs. On sales to Russia, firms must use a specific factor in addition to the other factors of production. The existence of the specific factor implies that additional output of firms can only come at increasing marginal costs. Imperfectly competitive Russian goods producers sell in all of Russia; but services firms do not sell in other Russian regional markets.

We employ the standard Chamberlinian large-group monopolistic competition assumption within a Dixit–Stiglitz framework, which results in constant markups over marginal cost. For simplicity we assume that the ratio of fixed to marginal cost is constant with respect to all factors of production for all firms producing under increasing returns to scale (in both goods and services). This assumption in a Dixit–Stiglitz-based Chamberlinian large-group monopolistic competition model assures that output per firm for all firm types remains constant, i.e. the model does not produce rationalization gains or losses. Similar to the Krugman (1980) model, our results will, however, differ from CRTS results to the extent that there are endogenous technology spillovers from the Dixit–Stiglitz variety effect.

An increase in the number of varieties increases the productivity of the use of imperfectly competitive goods based on the standard Dixit–Stiglitz formulation. The cost function for users of goods produced subject to increasing returns to scale declines in the total number of firms in the industry. The lower the elasticity of substitution, the more valuable is an additional variety.

We assume that imperfectly competitive firms within a regional market have symmetric cost structures and face symmetric demand for their outputs. It follows that all imperfectly competitive firms from a regional market will obtain the same price in any regional market of Russia in which they operate, although the price will differ across regional markets since the fixed costs associated with entering any regional market varies across the regional markets.

Imperfectly competitive business services with FDI Imperfectly competitive business services are supplied by foreign service providers on a cross-border basis, but a large share of business services are supplied by service providers with a domestic presence, both multinational and Russian.[15] Our model allows for both types of foreign service provision in these sectors. Cross-border services from the rest of the world, however, are not good substitutes for service providers who have a presence within the regional market of Russia where consumers of these services reside.

Russian firms providing imperfectly competitive business services operate at the regional level and organize production in a manner fully analogous to imperfectly competitive Russian firms producing goods. Thus, Figure 1 applies to both Russian imperfectly competitive goods and services firms. Other assumptions we made for imperfectly competitive goods producers, such as entry conditions, pricing and symmetry, also apply to imperfectly competitive services providers. The only difference is that we assume that regional services providers sell only in their own regional market or export.

Multinational service firm providers that choose to establish a presence in a regional market of Russia incur a fixed cost of operating in a regional market. As with imperfectly competitive goods producers, quasi-rents must cover the fixed plus marginal costs of producing in a regional market and because of free entry we have a zero-profit equilibrium.

For multinational firms, the barriers to FDI affect their profitability and entry. Reduction in the constraints on FDI in a region will induce foreign entry that will typically lead to productivity gains because when more varieties of service providers are available, buyers can obtain varieties that more closely fit their demands and needs (the Dixit–Stiglitz variety effect).

Trade Trade flows for perfectly competitive goods between regions and the rest of the world are specified following the Armington (1969) approach, which distinguishes goods by origin. Firm-level product differentiation characterizes trade for imperfectly competitive sectors. Regions are assumed to be price takers in the world market, i.e. the representation of the rest of the world is reduced to perfectly elastic import demand and export supply functions (export and import prices from the rest of the world are exogenous). Each region has a balance of trade constraint so that any change in the value of imports (either from the rest of the world or another regional market within Russia) is matched by an increase in the value of exports. Russia as a whole, represented as an aggregate of the regional markets, must satisfy an economy-wide balance of the trade constraint. The real exchange rate adjusts to assure that any change in the aggregate value of regional imports from the rest of the world, is matched by an equal change in the value of aggregate exports to the rest of the world.

Government Government demand across all regions is fixed at exogenous real levels. The government receives taxes to finance public expenditures. Public surpluses or deficits are balanced through lump-sum transfers with the representative households in each region.

Emissions The model tracks CO_2 emissions as well as six non-CO_2 pollutants: sulphur dioxide, nitrogen oxide, hydrocarbons, particulate matter, volatile organic components, and carbon monoxide. CO_2 emissions, which are by far the most important greenhouse gas emissions for Russia, are linked in fixed proportions to the use of coal, natural gas and refined oil products, with CO_2 coefficients differentiated by the specific carbon content of the fuels. CO_2 abatement can take place by fuel switching (inter-fuel substitution) or energy savings (either by fuel–non-fuel substitution or by a scale reduction of production and final demand activities or by more efficient production technologies that use less fuel per unit of output). All non-CO_2 emissions are linked in fixed proportions to output.

Data

Base-year input–output data determines the free parameters of the cost and expenditure functions such that the economic flows represented in the data are consistent with the optimizing behavior of the economic agents. In the following, we lay out our central data sources.

National input–output table The core input–output data are from the national 2001 input–output table produced by the Russian statistical office, Rosstat, containing only 22 sectors and little service sector disaggregation. In order to disaggregate the input–output table, we draw on cost shares and use shares from an expanded 35 sector Russian input–output table for 1995 (Rutherford and Tarr, 2008). To break up a composite sector such as oil and gas into specific subsectors, oil, gas and oil processing, we assume that the cost shares and use shares of the sector are the same in 2001 as they are in the 1995 table.

Regional input–output tables and trade flows of the regions We obtain data on 88 regions of Russia from *Regions of Russia* published by Rosstat (2003). We then construct input–output tables of the 88 regions that are based on data from the regions and the national input–output table. The input–output tables for our ten regional markets are aggregates of the input–output tables of the regions in their respective regional markets.

We assume that the technology of production is common across regions, so that the input–output coefficients from the national input–output table apply across all regions. As a first step, for each industrial sector, we take the national output from the national input–output table for 2001 and we use the data in *Regions of Russia* to allocate the shares of that output across the 88 regions. That is, from Rosstat (2001), we have, by region, the value of total industrial output and industry shares of regional industrial output for the year 2000 (see Table 13.3. in Rosstat, 2001).[16] This allows us to calculate the value of industry output by sector and region. For each industrial sector, we then proportionally scale the value of regional output so that the sum of industrial output across all regions is equal to the value of national output of the sector from the national input–output table.

We infer regional demand (and supply) of services, assuming that intermediate and final demand for services share a common intensity of demand in all regions as in the national model. For example, if telecommunications costs are x% of the costs of nonferrous metal production in the national model, we assume that telecommunications costs are x% of nonferrous metal costs in each of the regions.

Demand for telecommunications from nonferrous metals will differ across regions, however, since the share of total output attributable to nonferrous metals differs across regions.

We have total external exports and imports by region, as well as the commodity structure of external exports and imports by region for the year 2001 (Tables 23.1 and 23.2 in Rosstat, 2001). We also use Rosstat data on inter-regional exports and imports by sector. That is, for each of over 250 key commodities, we have an 88×88 matrix of bilateral trade flows among the regions.[17]

Supply and demand balance by region and by commodity requires adjustment of regional import and export trade intensities. These adjustments assure that region exports and imports on aggregate are consistent with national import and export values. We do this using a methodology that minimizes the sum of squares of the difference between the original data on exports and imports and the adjusted exports and imports data, subject to the constraints of supply–demand balance and consistency with the national model data. Since we have greater confidence in the validity of the regional output data than the inter-region trade flow matrix, in this optimization process, we fix the output levels of the regions at the levels that we calculated before.

Since in every step of the process we calculate region shares of the national input–output table, we may aggregate the 88 regions into a set of non-overlapping subsets and any such aggregation will yield a set of input–output tables that is fully consistent with the national input–output table. In particular, our 10-region, 30-sector model is consistent with the national input–output table.[18]

Emissions data With respect to environmental impacts of trade liberalization and the economic implications of emission control policies, emission intensities play a key role. The more emission intensive a sector is, the more adversely its production should be affected by pricing of emission inputs. Another key determinant of adjustment cost is the ease of substituting away from emission inputs as described through the nesting structure and the elasticities of substitution between inputs. In Table 1, we show emission intensities across Russian industries (the national average).[19] CO_2 emission intensities are composed of direct emissions from fossil fuel inputs, as well as indirect emission embodied in electricity inputs. Emission intensities in coal and gas production, electricity generation and pipeline transportation (including gas leakage) are the highest. Indirect emissions embodied in electricity play a secondary role for most sectors. Table 1 also shows emission intensities for non-CO_2 pollutants across industries.[20] Electricity generation, nonferrous and ferrous industries rank highest for sulphur dioxide emissions. These sectors also show substantial emission intensities for carbon monoxide, where crude oil production has by far the highest intensity. The release of hydrocarbons is predominantly associated with coal production and transportation activities.

Ad valorem *equivalents of barriers to fdi in services sectors* The business services sectors have been the subject of some of the most intense negotiations associated with Russian WTO accession. Russia has made numerous commitments in this area, including to foreign firms that provide environmental services. In many cases, Russia has implemented changes in the services sectors prior to accession to adapt to post-WTO requirements; in other cases, the commitments may be implemented only several years after accession owing to a negotiated adjustment period.[21] The counterfactual scenario that we implement in the business services sectors attempts to encapsulate all these cumulative reforms.

Estimates of the *ad valorem* equivalents of these and other barriers to FDI in services are central to the quantitative impact assessment of trade reforms. Building on a series of studies commissioned by the Australian Productivity Commission (Findlay and Warren, 2000) we estimate the *ad valorem* equivalents of barriers to FDI in several Russian sectors, namely, in telecommunications, banking, insurance and securities, and maritime and air transportation services.[22] The results of the estimates and the assumed reductions in the *ad valorem* equivalents of the barriers are listed in Table 2.

Tariff and Export Tax Data

Tariff rates by sector are based on the work of Shepotylo and Tarr (2013). They estimate the applied most favored nation (MFN) tariff rates at the 10-digit level in Russia for all years from 2001 to 2020. Based on these estimates, they provide aggregated tariff rates for the sectors of our model. From 2001 to 2011 inclusive, the estimates are based on actual tariff rates and trade data in Russia. Russia will implement its tariff commitments under its WTO accession agreement progressively from 2012 to 2020. For 2012 to 2020, Shepotylo and Tarr (2013) estimate changes in the *applied* MFN tariff based on the progressive tariff reduction commitments Russia has taken under its WTO accession agreement. Unlike in the case of services, there is evidence that Russia's tariff commitments did not impact its tariffs prior to 2012. Consequently, we take tariffs in 2011 as the benchmark tariff rates. We take the tariff rates in 2020 (when all tariff commitments are implemented) as the tariff rates in the counterfactual. These tariffs are reported in Table 2. Export tax rates were calculated by Jan Strelka from export values and volume data from the Russian Customs Service and from numerous regulations of the Russian Government on the tax rates, as explained in Jensen et al. (2004), and are reported in Table 2.

4. Policy Scenarios and Simulation Results

Policy Scenarios

One of our principal interests is the quantification of economic and environmental impacts associated with Russia's WTO accession. In our WTO accession scenario (executed without emission abatement policies) we assume that: (i) barriers to FDI are eliminated or reduced (depending on the sector); (ii) applied tariffs will fall according to the commitments of the Russian Federation as part of its WTO accession agreement; and (iii) for six Russian sectors that have been subjected to anti-dumping actions in export markets, we postulate better access to export markets that will lead to higher export prices ranging from 0.5% to 1.5% (see Table 2).

We then evaluate the cost effectiveness of three alternate "green" policy initiatives in Russia that are all designed to reduce CO_2 emissions by 20% from base-year emission levels. These are: (i) market-based cap and trade regulation; (ii) uniform emissions intensity standards; and (iii) uniform energy efficiency standards. Cap and trade regulation imposes a 20% reduction of CO_2 emissions in Russia through a system of tradable emission rights (or equivalently a nation-wide CO_2 tax).[23] Since marginal abatement costs of emissions are equilibrated across all users of fossil fuels under cap and trade, it is the least costly environmental regulation possible to achieve the objective. In the case of uniform emissions intensity standards, we require that all sectors

Table 2. Pre- and Post-WTO Accession Trade Distortions—(ad valorem %)

	Tariff rates				*Effective barriers to FDI (%)*	
	2011-Pre-WTO accession	*2020-final commitments*	*Export tax rates*	*Change in world market price*	*Pre-WTO accession*	*Post-WTO accession*
Electric industry	0.0	0.0	0.0	0.0		
Oil extraction	1.7	1	7.9	0.0		
Oil processing	5.1	4.9	4.6	0.0		
Gas	4.7	5	18.8	0.0		
Coal mining	4.4	4.4	0.0	0.0		
Ferrous metallurgy	8.6	5.9	0.4	1.5		
Nonferrous metallurgy	10	7.4	5.3	1.5		
Chemical & oil-chemical industry	7.4	5.2	1.6	1.5		
Mechanical engineering & metal-working	8.9	5.7	0.0	0.0		
Timber & woodworking & pulp & paper industry	14.3	8.2	6.9	0.0		
Construction materials industry	12.7	9.9	1.6	0.0		
Textiles and apparel	12.3	8.2	4.1	0.5		
Food industry	18.2	13.6	3.1	0.5		
Other industries	10.4	7.4	0.0	0.5		
Agriculture & forestry	7.7	5.7	0.6	0.0		
Other goods-producing sectors	14.2	10.7	0.0	0.5		
Telecommunications					33.0	0.0
Science & science servicing (market)					33.0	0.0
Financial services					36.0	0.0
Railway transportation					33.0	0.0
Truck transportation					33.0	0.0
Pipelines transportation					33.0	0.0
Maritime transportation					95.0	80.0
Air transportation					90.0	75.0
Other transportation					33.0	0.0

Sources: Shepotylo and Tarr (2013) for tariff rates; Jensen et al. (2004) for barriers to FDI and for export tax rates and authors' estimates for change in world market prices.

and regions except for fossil fuel sectors (coal, crude oil and gas,) uniformly reduce the intensity of their CO_2 emissions per unit of the value of output produced. We solve iteratively for the uniform reduction in the intensity of CO_2 emissions such that a 20% reduction in CO_2 emissions is achieved. In the case of uniform energy efficiency standards, we require that in all regions, all sectors except electricity and fossil fuel production (crude oil, coal and natural gas) equi-proportionately reduce their use of gas, refined oil, and electricity per unit of output. As with emissions intensity standards, we solve iteratively for uniform adjustments in energy intensity such that a 20% reduction in CO_2 emissions is achieved.[24]

As stated in the introduction, Antweiler et al. (2001) and Grossman and Krueger (1993) provide evidence of endogeneity of trade and environment policies in that trade liberalization tends to be accompanied by greater environmental regulation. In this vein, we also execute three additional scenarios in which we assess the impacts of "overlapping" policy reforms. In these scenarios we simultaneously implement our WTO accession policy changes with each of our three CO_2 emission reduction policy initiatives. In particular, for the scenario that combines cap and trade with WTO accession policy commitments, Table 3 presents the full economic and environmental impacts for all 10 of our regional markets for the scenario. Owing to space constraints, we only present results for the other six policy scenarios for the Russian economy as a whole. These results are presented in Table 4. For the full regional market results, see Böhringer et al. (2014) where we show results for all 30 sectors in all 10 regional markets, including results for welfare, emissions of our seven pollutants, changes in exports, imports, employment at the sector level, factor returns and the real exchange rate.

Environmental and Economic Impacts of WTO Accession

Overall economic impacts As shown in Table 3, if we combine the WTO policy changes with CO_2 reduction by 20% through cap and trade, the estimated overall welfare gains are 7.2% of consumption, with considerable differences across regions. In Table 4, we show the economy-wide estimated gains for all seven scenarios. In particular, our cap and trade policy costs 1.4% of consumption since without additional environmental regulation, the estimated overall Russian economy average welfare gain from WTO accession is 8.6% of consumption.[25] Rutherford and Tarr (2008) reveal that the source of the largest gains from Russia's WTO accession is the reduction in barriers against foreign investors in services—accounting for about 70% of the total gains. Consistent with the econometric evidence cited above, in our model new services providers increase the productivity of sectors that use services. Russian commitments to reduce barriers against multinational service providers will allow multinationals to obtain higher after tax returns on their investments in Russia and thus initially create positive profits. This will induce the multinationals to increase FDI to supply the Russian market until the additional entry restores a zero-profit equilibrium. Although we find that there is some decline in the number of purely Russian-owned businesses serving the services markets, on balance there will be additional service providers. Russian users of business services will then have improved access to the providers of services in areas like telecommunication, banking, insurance, transportation and other business services.

Region-specific economic impacts The differences across regional markets in Table 3 are primarily explained by two considerations: (i) the ability of the different regional

Table 3. WTO Accession with CO_2 Cap and Trade—IRTS Model

	Overall average	*Moscow*	*St Peters*	*Tumen*	*Northwest*	*North*	*Central*	*South*	*Urals*	*Siberia*	*Far East*
Aggregate welfare											
Welfare (EV as % of consumption)	7.2	5.5	9.7	13.7	12.5	9.2	8.4	7.4	6.4	7.5	8.5
Welfare (EV as % of GDP)	3.3	3.0	4.4	2.9	5.8	3.8	3.9	3.5	2.9	3.5	3.8
CO_2 emissions and decomposition											
CO_2 price (ruble per ton of CO_2)	0.0	112.4	112.4	112.4	112.4	112.4	112.4	112.4	112.4	112.4	112.4
CO_2 emissions (% change), decomposed into:	–20.0	–19.0	–17.7	–22.0	–18.8	–18.1	–19.1	–17.8	–21.3	–20.8	–18.3
–Output effect (% of CO_2)	3.6	3.5	5.9	2.3	6.0	5.2	4.0	4.0	2.5	3.8	5.3
–Composition effect (% of CO_2)	–3.6	–1.0	–0.7	–11.4	–2.7	–3.4	–1.3	–1.5	–3.0	–5.2	–2.9
–Technique effect (% of CO_2)	–19.5	–20.8	–21.6	–13.1	–20.9	–19.1	–21.1	–19.7	–20.7	–19.1	–19.8
Non-CO_2 emissions (% change)											
Sulphur dioxide	5.9	1.6	11.7	–2.6	–8.6	7.4	–2.9	2.7	5.3	7.3	5.2
Nitrogen oxide	–1.3	–2.9	0.3	–1.4	1.3	–0.1	–1.9	–1.6	–1.7	0.0	–1.0
Hydrocarbons	–3.6	–4.7	0.6	–0.5	1.2	–3.4	–2.0	–1.7	–2.8	–10.7	–16.7
Particulate matter	–0.6	–3.2	–0.4	–0.3	0.1	0.7	–2.1	–2.1	–1.2	1.0	–0.4
Volatile organic components	0.8	–1.6	2.2	0.9	17.6	1.4	9.2	1.9	–0.1	–1.5	3.3
Carbon monoxide	2.2	9.5	6.0	0.7	–9.2	4.1	–3.4	2.3	1.8	5.2	3.1
Aggregate trade (% change)											
Regional terms of trade	2.8	14.0	15.5	12.6	14.6	14.5	13.7	13.4	12.4	13.0	14.6
Regional exports	1.4	1.5	2.3	0.9	2.4	1.9	2.5	1.6	1.4	0.4	2.1
Real exchange rate	2.4	2.5	3.3	1.9	3.5	2.6	3.2	2.6	1.9	1.7	2.6
International exports	8.2	16.0	13.6	3.9	12.7	9.0	10.0	9.6	8.9	7.2	13.1
Return to primary factors (% change)											
Unskilled labor	1.6	2.2	4.4	1.0	4.8	2.7	2.2	2.3	0.0	1.0	3.2
Skilled labor	0.3	0.7	3.7	–1.2	3.2	1.3	1.6	1.5	–0.4	–1.8	1.7
National capital	1.6	1.7	2.5	1.1	2.7	1.8	2.4	1.8	1.1	0.9	1.8
Regional mobile capital	3.6	3.4	6.3	4.2	5.8	5.2	3.4	3.7	2.4	3.7	5.7
Crude oil resources	3.8	0.0	0.0	3.6	5.8	5.3	0.0	5.5	3.4	2.9	5.3
Natural gas resources	–33.4	0.0	0.0	–34.1	–28.4	–30.6	0.0	–23.9	–26.3	–34.1	–33.6
Coal resources	–9.2	0.0	0.0	0.0	0.0	–6.5	–4.7	–6.2	–9.9	–10.0	–7.0
Specific capital in domestic firms	0.0	–29.9	–21.5	–48.5	–21.9	–25.5	–17.4	–25.0	–18.2	–18.8	–27.1
Specific capital in multinational firms	0.0	59.3	48.4	217.4	77.4	139.6	113.4	125.9	139.0	159.2	113.6
Factor adjustments											
Unskilled labor (% changing sectors)	2.1	1.8	2.1	2.5	2.8	2.3	1.8	1.4	2.4	2.6	3.2
Skilled labor (% changing sector)	2.9	2.4	2.6	3.1	3.3	3.4	2.3	1.9	2.7	4.4	4.4

Source: Authors' estimates.

Table 4. Nation-wide Impacts—IRTS Model

		WTO accession plus:			*CO_2 reduction policies alone:*		
	WTO accession only	*CO_2 emissions cap and trade*	*Emissions intensity standards*	*Energy intensity standards*	*CO_2 emissions cap and trade*	*Emissions intensity standards*	*Energy intensity standards*
Aggregate welfare							
Welfare (EV as % of consumption)	8.6	7.2	6.4	0.6	–1.1	–1.7	–5.9
Welfare (EV as % of GDP)	4.0	3.3	3.0	0.3	–0.5	–0.8	–2.7
CO_2 emissions and decomposition							
CO_2 price (ruble per ton of CO_2)		112.4			96.0		
CO_2 emissions, decomposed into:	4.3	–20.0	–19.2	–19.7	–20.0	–20.0	–19.8
–Output effect (% of CO_2)	4.9	3.6	2.7	–3.0	–1.0	–1.8	–6.1
–Composition effect (% of CO_2)	1.0	–3.6	–0.4	–6.5	–3.1	–1.0	–6.0
–Technique effect (% of CO_2)	–1.6	–19.5	–20.3	–10.6	–16.3	–17.1	–8.2
Non-CO_2 emissions (% change)							
Sulphur dioxide	6.2	5.9	7.1	–1.3	–0.1	1.0	–6.9
Nitrogen oxide	2.8	–1.3	5.1	–16.4	–3.3	2.0	–16.1
Hydrocarbons	1.7	–3.6	–2.6	–6.4	–4.2	–3.6	–6.5
Particulate matter	3.0	–0.6	4.3	–12.0	–2.9	1.1	–12.5
Volatile organic components	2.7	0.8	1.1	–5.8	–1.5	–1.4	–6.8
Carbon monoxide	4.5	2.2	3.0	–1.2	–1.7	–1.2	–4.7
Aggregate trade (% change)							
Regional terms of trade	2.9	2.8	2.2	0.9	–0.1	–0.6	–1.5
Regional exports	3.0	1.4	1.4	–6.2	–1.2	–1.3	–7.5
Real exchange rate	1.8	2.4	1.5	1.6	0.4	–0.3	–0.2
International exports	8.1	8.2	7.5	6.3	0.4	–0.4	–1.2
Return to primary factors (% change)							
Unskilled labor	3.7	1.6	3.6	3.1	–1.7	0.0	0.0
Skilled labor	3.7	0.3	3.9	2.5	–2.6	0.3	–0.4
National capital	3.8	1.6	2.4	–0.8	–1.7	–1.1	–3.4
Regional mobile capital	5.8	3.6	4.9	1.5	–1.8	–0.7	–3.1
Crude oil resources	4.4	3.8	1.6	–3.3	–0.6	–2.4	–6.4
Natural gas resources	7.0	–33.4	–44.2	–33.1	–32.9	–42.7	–32.0
Coal resources	9.7	–9.2	–0.7	5.0	–13.6	–7.9	–3.2
Factor adjustments							
Unskilled labor (% changing sectors)	2.0	2.1	2.1	2.9	0.9	0.7	2.2
Skilled labor (% changing sector)	2.6	2.9	2.8	3.5	1.5	1.1	2.7

Source: Authors' estimates.

markets to benefit from a reduction in barriers against FDI; and (ii) the differences in CO_2 emissions intensities across regions. To diagnose the relative importance, first consider WTO accession *without environmental regulation*. Then the regional markets that gain the most from WTO accession as a percentage of GDP are Northwest (5.6%), St Petersburg (5.2%) and Far East (4.8%). Our dataset shows that these three regional markets have the largest shares of multinational investment (along with the North regional market, which also gains substantially).[26] The Urals, which has relatively little FDI in the services sectors, has the lowest estimated gains at 3.3% of GDP. In contrast, under *cap and trade without WTO accession policies*, the welfare losses (as a percentage of GDP) are greatest for the regional markets of Saint Petersburg (−0.6%), Far East (−0.8%) and Moscow (−1.0%). We find that the Northwest regional market is a net seller of emissions permits, it does not lose welfare from cap and trade CO_2 regulation. (It does lose welfare from the less efficient emissions regulations.) Netting out the costs of CO_2 regulation explains why the Northwest regions stands out as the principal gainer in terms of an increase in GDP from WTO accession combined with cap and trade.

Decomposing the impacts of WTO accession and CO_2 emissions Grossman and Krueger (1993) as well as Copeland and Taylor (1994, 1995) decompose the overall environmental (emission) impact of trade liberalization into three components: scale, composition and technique. The scale effect refers to an increase in emissions associated with a larger GDP, holding constant the relative mix of outputs and pollution intensities across sectors. The composition effect refers to a change in the share of dirty goods in GDP. The technique effect refers to a change in the amount of emissions per unit of output across sectors.

CRTS models are driven by the theory of comparative advantage and thereby focus primarily on composition effects.[27] With increasing returns to scale and imperfect competition, however, both scale and technique effects are more prominent. Productivity changes emerge through trade liberalization owing to rationalization gains or because the number of product varieties and technologies increase. With IRTS this would likely lead to more pollution from the scale effect, but less resource use per unit of output and less pollution from the technique effect.[28] Further, if trade liberalization leads to an expansion of dirty industries subject to IRTS technology, pollution problems will be exacerbated owing to the scale and composition effects compared with a CRTS reference. In contrast, IRTS will likely lead to greater income gains and the capacity to pay for environmental regulation.

To gain insights into their direction and magnitude we quantify the scale, composition and technique effects of WTO accession in Russia on CO_2 emissions and compare the total and decomposed effects in our central IRTS model with those generated in the more conventional CRTS model (see section 5). We decompose emissions into the scale, composition and technique effects based on the following methodology.

Let E = emissions, Y = the value of aggregate output, a_i = emissions per unit of the value of output of sector i, y_i = the value of output of sector i and θ_i = the share of sector i's output in the economy. With n sectors in the economy, aggregate emissions are:

$$E = \sum_{i=1}^{n} a_i y_i \tag{1}$$

since $y_i = \theta_i Y$, we have

$$E = Y\sum_{i=1}^{n} a_i\theta_i. \tag{2}$$

It follows that, in the neighborhood of the equilibrium, the percentage change in emissions can be decomposed into:

$$\frac{\Delta E}{E} = \frac{\Delta Y}{Y} + \frac{\sum_i a_i \Delta\theta_i}{\sum_i a_i\theta_i} + \frac{\sum_i \theta_i \Delta a_i}{\sum_i a_i\theta_i} \tag{3}$$

The first term on the right-hand side of equation (3) is the scale effect, the second term is the composition effect and the third term is the technique effect. In all of our scenarios, we show the percentage change in CO_2 emissions in total and owing to each of these three effects for each of the 10 regions of our Russia model and an overall average for the Russian economy.[29]

Tables 4 and 5 reveal that despite a positive impact on the environment from the technique effect, the relative expansion of dirty industries in Russia and the scale effect dominate so that, in either our IRTS or CRTS models, WTO accession alone will increase environmental pollution. Primarily because of larger output expansion in our IRTS model, we estimate a larger increase in pollution from WTO accession in our IRTS model.

We also show below that the decomposition of impacts varies drastically between WTO accession alone and our central scenario of WTO accession combined with cap and trade regulation. WTO accession alone increases aggregate CO_2 emissions by 4.3%. The main reason for the increase in emissions is the increase in output, which increases CO_2 emissions of 4.9%. The composition effect also increases emissions in the case of Russia by 1.0%. While the composition effect is ambiguous in general, the reason it has an adverse environmental impact in Russia is that two of the relatively dirty industries, namely ferrous metals and chemicals and petrochemicals, are (along with nonferrous metals) the sectors that expand the most.[30] Ferrous metals output expands in all nine of the regions in which it is produced. Output of chemicals and petrochemicals expands in all 10 regions. The reason that these sectors along with nonferrous metals output expand the most is that trade liberalization, in general, tends to benefit export-intensive sectors; export-intensive sectors experience the benefit of the removal of the anti-export bias of trade protection realized through a depreciated real exchange rate. In the case of Russia, it is ferrous metals, nonferrous metals and chemicals that intensively export (two of which intensively emit CO_2), while the relatively cleaner sectors, such as food and light industry, which do little exporting, decline in most regions. While the technique effect works toward reducing CO_2 emissions, it is relatively small at 1.6%. The technique effect in this scenario can be traced back to increased productivity with existing resources as a result of the Dixit–Stiglitz productivity externality from additional varieties of imperfectly produced goods and services and a shift toward less fossil-fuel-intensive forms of production.

Cost of Alternate CO_2 Emission Reduction Policies

We take a cleaner environment as an objective desired by the authorities and assess different environmental regulations in terms of their economic costs, and by

Table 5. *Nation-wide Impacts—CRTS Model*

	WTO accession only	*WTO accession plus:* CO_2 *emissions cap and trade*	*WTO accession plus:* *Emissions intensity standards*	*WTO accession plus:* *Energy intensity standards*	*CO_2 reduction policies alone:* CO_2 *emissions cap and trade*	*CO_2 reduction policies alone:* *Emissions intensity standards*	*CO_2 reduction policies alone:* *Energy intensity standards*
Aggregate welfare							
Welfare (EV as % of consumption)	1.1	0.7	0.0	−3.5	−0.4	−1.0	−4.1
Welfare (EV as % of GDP)	0.5	0.3	0.0	−1.6	−0.2	−0.4	−1.9
CO_2 emissions and decomposition							
CO_2 price (ruble per ton of CO_2)		107.8			103.4		
CO_2 emissions, decomposed into:	1.0	−20.0	−20.4	−20.2	−20.0	−19.9	−19.9
–Output effect (% of CO_2)	1.1	0.4	−0.4	−4.7	−0.7	−1.4	−5.3
–Composition effect (% of CO_2)	0.4	−2.4	−0.9	−6.2	−2.5	−1.2	−6.1
–Technique effect (% of CO_2)	−0.4	−18.0	−18.6	−9.7	−17.2	−17.3	−8.8
Non-CO_2 emissions (% change)							
Sulphur dioxide	4.6	4.5	5.2	−4.7	−0.4	0.6	−8.9
Nitrogen oxide	0.9	−2.1	3.1	−16.5	−2.9	2.1	−16.4
Hydrocarbons	0.1	−4.5	−3.8	−7.1	−4.3	−3.6	−6.7
Particulate matter	1.1	−1.4	2.4	−12.5	−2.5	1.2	−12.9
Volatile organic components	0.1	−1.1	−1.0	−6.7	−1.1	−1.1	−6.4
Carbon monoxide	1.9	0.5	0.6	−3.6	−1.4	−1.2	−5.2
Aggregate trade (% change)							
Regional terms of trade	1.0	1.1	0.7	0.1	0.1	−0.3	−0.8
Regional exports	0.2	−0.9	−1.0	−7.7	−1.1	−1.1	−7.4
Real exchange rate	0.2	0.7	0.0	0.4	0.4	−0.2	0.2
International exports	2.1	2.0	1.7	−0.1	−0.1	−0.4	−2.0
Return to primary factors (% change)							
Unskilled labor	1.2	−0.3	1.7	2.7	−1.5	0.5	1.5
Skilled labor	1.6	−0.9	2.4	2.5	−2.4	0.8	0.9
National capital	1.4	−0.1	0.7	−1.2	−1.5	−0.7	−2.4
Regional mobile capital	1.9	0.2	1.6	−0.3	−1.6	−0.2	−1.9
Crude oil resources	0.2	−0.1	−1.6	−5.8	−0.3	−1.7	−5.7
Natural gas resources	0.4	−35.4	−45.9	−35.2	−33.8	−43.0	−32.8
Coal resources	0.6	−12.2	−7.6	−0.5	−12.2	−7.3	−0.9
Factor adjustments							
Unskilled labor (% changing sectors)	0.8	0.9	1.2	2.5	0.7	0.7	2.3
Skilled labor (% changing sector)	0.9	1.4	1.5	3.0	1.3	1.0	2.7

Source: Authors' estimates

implication, political feasibility. More specifically, we assess three alternate policies to reduce CO_2 emissions by 20% from base-year emission levels: cap and trade, emission intensity standards and energy efficiency standards. Results of all three policies are shown for the overall economy average in Table 4.

CO_2 mitigation with "cap and trade" We find that a policy of using a system of tradable emission rights to achieve a 20% CO_2 emission reduction would cost 0.5% of GDP in aggregate. From our decomposition analysis, we see that the reduction in CO_2 emissions is accomplished primarily through the technique effect. Although there is a modest 1% reduction in emissions through output reduction and a shift to cleaner industries results in a 3.1% reduction in CO_2 emissions, the technique effect accounts for over a 16% reduction in CO_2 emissions. Since there are virtually no productivity gains in this scenario, unlike our WTO accession scenario, the technique effect derives from fuel switching toward fuels that emit fewer CO_2 emissions and a switch to less fuel-intensive forms of production.

CO_2 emission intensity standards We find that the impact of requiring a uniform reduction in the intensity of CO_2 emissions per unit of the value of output produced at the sector and regional level (coal, crude oil and gas production excluded) to achieve a 20% reduction in CO_2 emissions costs about 0.8% of GDP. Again, it is the technique effect that dominates the adjustment in CO_2 emissions, accounting for a 17.1% reduction in CO_2 emissions. The switch to clean industries (the composition effect) is much weaker in this scenario than under emissions trading or energy efficiency standards, since all sectors must reduce the intensity of their emissions uniformly, even if they start with fewer emissions per ruble of output. Under this regulation, there is no incentive to switch production to clean industries since it does not help achieve the regulatory target. Despite this inefficiency, compared with cap and trade, the additional costs of achieving the 20% reduction in CO_2 emissions are only 0.3% of GDP. The relatively small additional cost of this "command and control" regulation compared with a market-based system can be attributed to the fact that "emissions intensity" still targets rather closely the reduction in CO_2 emissions.

Energy efficiency standards In this scenario we require that in all regions, all sectors except electricity and fossil fuel production (crude oil, coal and natural gas) must equi-proportionately reduce their use of gas, refined oil and electricity to achieve an aggregate 20% reduction in CO_2 emissions. We find that a uniform requirement to cut fossil fuel use by 25%, results in the exogenously mandated 20% reduction in CO_2 emissions. The cost in terms of loss in GDP, however, is a very substantial 2.7% of GDP, more than five times the cost of the emissions trading system to achieve the same CO_2 emissions reduction. The higher cost of achieving CO_2 emission reduction is partly due to the lack of adjustments of a market-based system; but our results show that even more important is the fact that, compared with emissions intensity standards, energy efficiency standards do not closely target the objective of lower CO_2 emissions.

On the positive side for energy efficiency standards is that they achieve a much greater reduction in non-CO_2 emissions than CO_2 emissions trading or CO_2 emissions intensity standards. This is especially true regarding nitrogen oxide and particulate matter, where energy efficiency standards achieve a double digit percentage reduction. This is in line with the conclusion of Goulder and Parry (2008), who argue that no single instrument is clearly superior along all dimensions relevant to policy choice.

WTO Accession Joint with CO_2 Emissions Reduction Policies

CO_2 emission markets When we combine WTO accession with a regulation to cut CO_2 emissions by 20% through CO_2 emissions trading, we estimate that the overall welfare gains fall to 7.2% of consumption compared with 8.6% of consumption from WTO accession independently; nonetheless, the overall welfare gains remain high. Interestingly, adding cap and trade regulation on CO_2 emissions to WTO accession results in a change in the sign of the composition effect compared with WTO accession alone. The reason is that our two dirty industries that were among the strongest expanders under WTO accession alone are now among the biggest contractors. The chemicals and petrochemicals sector declines in eight of the 10 regions and the ferrous metals sector declines in all sectors where it is produced. In addition, oil and gas production as well as pipeline transportation decline in this scenario. The technique effect becomes even more important in this scenario, as it is responsible for a decline of 19.5% in total CO_2 emissions. The Tumen regional market is an outlier regarding the strong composition effect contributing to a reduction in its CO_2 emissions. This is explained by the fact that Tumen produces 90.8% of the gas and 62.8% of the crude oil in Russia. In addition to switching away from fossil fuel use, the productivity gains of WTO accession allow production of output with fewer fossil fuels.

Emissions intensity standards When we combine WTO accession with CO_2 emission intensity standards, the estimated welfare gain of 6.4% of consumption remains substantial; but this is a further reduction of 0.8% of consumption compared with cap and trade combined with WTO accession. As mentioned above, the switch to clean industries (the composition effect) is relatively weak owing to the lack of incentive to switch production to clean industries with this regulation. Consequently, in this policy simulation, the technique effect is the strongest of all seven of our core policy scenarios.

Energy efficiency standards In this scenario, we combine WTO accession with energy efficiency standards. The welfare gains fall very substantially to 0.6% of consumption. Thus, judged on the basis of CO_2 emissions alone, this policy is by far the most costly. Although emissions intensity standards are more costly than cap and trade for achieving CO_2 emissions reduction, they are much more efficient than energy emission standards. We can see, however, that energy efficiency standards to achieve CO_2 emissions reduction is considerably more effective at achieving a reduction in emissions other than CO_2. In fact, energy efficiency standards are more effective at reducing all six non-CO_2 emissions.

5. Comparison with CRTS Model Version

In this section, we investigate the impact of our more innovative and empirically accurate IRTS modeling framework by executing our seven basic scenarios in a model with constant-returns-to-scale and perfect competition. In Table 5, we show the aggregate results for the overall economy of all of our seven basic scenarios in a CRTS perfect competition model. Table 5 is directly comparable with Table 4, where the latter is based on our central model with increasing returns to scale and FDI in services. Crucially, we find there is a change in the sign of the welfare impact for WTO accession combined with the two least efficient environmental regulation policies to reduce CO_2 emissions.

In either our WTO accession or WTO accession plus environmental regulation combined scenarios, the estimated welfare gains are substantially larger with the IRTS model. The smaller estimated welfare gains with the CRTS model are what is expected in models that assess welfare changes through "Harberger triangles." Crucially, a key result of the analysis with our central IRTS model is reversed with the CRTS model. We find that with IRTS, WTO accession is expected to expand incomes by more than enough to pay for the cost of emission reduction, even if the least efficient policy of environmental regulation is used. With CRTS, simultaneous application of WTO accession and environmental regulation yields net benefits only if the market-based cap and trade system is employed, and a substantial loss if the least efficient environmental policy is employed. When simultaneously applied with WTO accession, our least efficient environmental policy of energy efficiency standards, yields a net welfare loss of 1.6% of GDP. These results show that there are larger net gains available when taking IRTS into account, which allow for net gains after regulation to produce a net cleaner environment.

In contrast, assessing WTO accession or the WTO accession plus emission abatement, we see that the CRTS model shows less of an adverse impact on the environment for all seven pollutants in our WTO accession scenario. The reason is that the productivity effects of the model with IRTS and FDI leads to greater output expansion, which results in more emission of pollutants. In the case of CO_2 emissions, our decomposition analysis shows that the scale effect on CO_2 emissions, which is the primary culprit in the increase in CO_2 emissions with IRTS, is much smaller in the CRTS model.

6. Piecemeal Sensitivity Analysis

We focus on the scenario in which we combine WTO accession with a 20% reduction of CO_2 emissions through emission trading. For the sake of compactness, Table 6 presents the results for the aggregate economy only. In these scenarios, we retain the central value of all parameters except the parameter in question. As far as welfare is concerned, the gains to the economy generally increase with an increase in elasticities, since higher elasticities imply that the economy is able to more easily shift to sectors or products that are cheaper after trade and FDI liberalization.[31] There are two parameters in Table 6 that show a strong impact on the results: the elasticity of substitution between value-added and business services (*esubs*) and the elasticity of multinational firm supply (*etaf*). A liberalization of the barriers to FDI will result in a reduction in the cost of business services, both from the direct effect of lowering the costs of doing business for multinational service providers and from the indirect effect that additional varieties of business services allow users to purchase a quality adjusted unit of services at lower cost. When the elasticity of substitution between value-added and business services is high (*esubs* = 2 in Table 6), users have a greater potential to substitute the cheaper business services and this increases productivity. The elasticities of multinational and Russian firm supply (*etaf, etad*) are primarily dependent on the sector-specific factor for each firm type (foreign or domestic). When *etaf* is high, a reduction in the barriers to FDI results in a larger expansion in the number of multinational firms supplying the Russian market and, hence, more gains from additional varieties of business services. In addition, the share of the services market captured by multinationals has a strong effect, since a liberalization results in a larger number of new varieties introduced.

Table 6. Sensitivity Analysis—IRTS Model

Parameter being changed	*Welfare effects*		*CO_2 emissions (% change)*				*Non-CO_2 emissions (% change)*					
	EV % of: consumption	*GDP*	*Total CO_2*	*Output effect*	*Composition effect*	*Technique effect*	*Sulphur dioxide*	*Nitrogen oxide*	*Hydro-carbons*	*Particulate matter*	*Volatile organics*	*Carbon monoxide*
Central Results for reference	7.2	3.3	–20.0	3.6	–3.6	–19.5	5.9	–1.3	–3.6	–0.6	0.8	2.2
esubconsumer = 1.5	7.4	3.5	–20.0	3.7	–3.7	–19.6	5.8	–1.4	–3.4	–0.6	0.8	2.2
esubconsumer = 0.5	6.5	3.0	–20.0	3.2	–3.2	–19.5	6.0	–1.0	–4.1	–0.4	0.7	2.2
esubs = 2.0	9.5	4.4	–20.0	5.6	–3.8	–21.0	6.3	0.0	–1.1	0.4	1.6	2.8
esubs = 0.5	5.7	2.6	–20.0	2.2	–3.4	–18.6	5.6	–2.1	–5.2	–1.2	0.2	1.8
sigmadm = 4	7.3	3.4	–20.0	3.5	–3.7	–19.4	6.1	–1.2	–3.8	–0.4	0.9	2.4
sigmadm = 2	6.3	2.9	–20.0	3.3	–3.3	–19.6	5.9	–1.6	–3.3	–1.0	0.2	1.8
etaf = 17.5	8.1	3.8	–20.0	4.1	–3.6	–19.9	5.7	–1.1	–3.4	–0.5	1.2	2.4
etaf = 12.5	6.1	2.8	–20.0	2.9	–3.5	–19.1	6.0	–1.6	–3.8	–0.8	0.3	2.0
etad = 10	7.5	3.5	–20.0	3.4	–3.8	–19.2	7.1	–1.3	–4.1	–0.5	0.5	2.6
etad = 5	6.8	3.1	–20.0	3.8	–3.3	–20.0	4.5	–1.2	–2.9	–0.6	1.1	1.8
esub = 4	7.2	3.4	–20.0	3.5	–3.6	–19.4	6.0	–1.3	–3.8	–0.5	1.0	2.5
esub = 2	6.2	2.9	–20.0	3.4	–3.3	–19.6	5.7	–1.6	–3.4	–0.9	0.1	1.6
esubprimary = 1.5	7.2	3.3	–20.0	3.6	–3.6	–19.6	6.0	–1.3	–3.8	–0.6	0.6	2.2
esubprimary = 0.5	7.2	3.3	–20.0	3.6	–3.5	–19.5	5.5	–1.2	–3.2	–0.5	1.1	2.3
etadx = 7	7.2	3.4	–20.0	3.6	–3.8	–19.4	5.9	–1.4	–3.7	–0.7	0.7	2.2
etadx = 3	7.0	3.3	–20.0	3.5	–3.3	–19.8	5.7	–1.2	–3.5	–0.4	0.9	2.2

Notes: esubconsumer = Elasticity of substitution in consumer demand (central value (cv) = 1); esubs = Elasticity of substitution between value-added and business services (cv = 1.25); sigmadm = "Armington" elasticity of substitution between imports and domestic goods in CRTS sectors (cv = 3); Etaf = Elasticity of multinational service firm supply with respect to price of output (cv = 15); Etad = Elasticity of Russian service firm supply with respect to price of output (cv = 7.5); esub = Elasticity of substitution between firm varieties in imperfectly competitive sectors (cv = 3); esubprimary = Elasticity of substitution between primary factors of production in value added (cv = 1); Etadx = Elasticity of transformation (domestic output versus exports) (cv = 5).
Source: Authors' estimates.

Regarding the sensitivity results for WTO accession alone, in general, both welfare and emissions increase with the elasticities (results not shown). Greater elasticities lead to greater output expansion and greater emissions. The same pattern tends to hold for our results in Table 6 and our results appear robust. The largest range of results for emissions is with respect to the parameter *eubs*. Volatile organic components, particulate matter, nitrogen oxide and especially hydrocarbons are sensitive to the parameter *esubs*. For low values of *esubs*, value-added does not substitute well for business services, so when reforms reduce the quality adjusted price of business services, there is less substitution of business services, then less of a variety externality and less output expansion.

7. Conclusions

Using our IRTS model, we find that WTO accession alone will increase environmental pollution in Russia. We estimate an expansion of dirty industries in Russia and our decomposition shows that the negative effect on the environment of the composition effect (especially the relative expansion of dirty industries) and the expansion of output (scale effect) dominate the positive impact on the environment of the technique effect (which includes importing new more efficient technologies, processes and services). We show that primarily because of a larger output expansion in our IRTS model, there is a larger increase in pollution from WTO accession alone in our IRTS model compared with a more traditional CRTS model.

Given the evidence of endogenous interaction between trade liberalization and environmental regulation, we assess the costs of three types of environmental regulations to reduce CO_2 emissions by 20% and we execute three simulations in which we combine WTO accession with each of these emission abatement policies. We find that despite the fact that there is a larger increase in pollution with the IRTS model in first place, CO_2 emissions can be reduced by complementary environmental policies while still retaining substantial welfare gains from trade liberalization. Notably, in a CRTS model, there are no net welfare gains with the two least efficient environmental regulation policies. This shows that the choice of the appropriate model is crucial, as even the sign of the impact can be wrong if the wrong model is chosen. Moreover, while our results are consistent with earlier models that suggest increased pollution with IRTS models (absent offsetting environmental regulations), our results show that there are greater gains available when taking IRTS into account, which allow for net gains after regulation to produce a net cleaner environment.

We find that cap and trade is the most efficient policy for CO_2 emissions, as expected. Emissions intensity standards are less efficient than cap and trade in part since there is no incentive to switch sectors, but we find that the costs of emissions intensity standards are drastically lower than the costs of energy efficiency standards, as the former operate more closely to the relevant margin.

While many studies have compared the cost-effectiveness of different emission abatement policies using CGE models, our analysis—to our best knowledge—is the first general equilibrium assessment to compare the economic efficiency of different environmental regulations using an IRTS model. This paper highlights that when we estimate the combined impact of trade liberalization and environmental policies, even the sign of the result depends on the choice of the market structure.

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Notes

1. For surveys, see Hertel (1997), Conrad (2001), Dean (2002), Bovenberg and Goulder (2002), Bergman (2005), Frankel and Rose (2005), and Carbone and Rivers (2014).
2. Babiker (2005) employs a model of Cournot oligopoly to assess the economic impacts of the Kyoto Protocol. His model allows rationalization gains or losses, which magnifies the losses of countries limiting their emissions compared with perfect competition. Böhringer et al. (2008) also employ a model of Cournot oligopoly and similarly find that the losses from emission regulation are magnified with imperfect competition.
3. See Francois and Hoekman (2010) for a survey of empirical studies that support the finding of productivity effects from additional business services. Studies that use firm-level data include Arnold et al. (2011) for the Czech Republic, Fernandes and Paunov (2012) for Chile, Shepotylo and Vakhitov (forthcoming) for Ukraine and Arnold et al. (forthcoming) for India.
4. See Tarr and Volchkova (2013).
5. See Ministry of Natural Resources and Environment of the Russian Federation (2014).
6. According to Rosgidromet (2013): "In 138 cities in Russia (57% of the urban population), the level of air pollution is characterized as high or very high."
7. On 5 November 2004, Russia ratified the Kyoto Protocol, which facilitated the Protocol entering into force in February 2005. Under the Kyoto Protocol, Russia committed to limit its annual emissions of greenhouse gases at 1990 emission level—3048 million tons of CO_2 equivalent ($MtCO_2e$)—over the period 2008–2012.
8. See of Ministry of Natural Resources and the Environment of the Russian Federation (2014).
9. See of Ministry of Energy of the Russian Federation (2010).
10. A detailed algebraic description of the core model is available as an appendix to Jensen et al. (2004).
11. For details of the mappings and data, see Tables 2–11 in Böhringer et al. (2014).
12. See Rutherford and Tarr (2010) for an explanation of the representative agent's share of the income of the national mutual fund.
13. For fossil fuel production, we assume decreasing returns to scale: value-added and all goods and services form a Leontief composite input that substitutes in a CES nest with a sector-specific resource. The elasticities of substitution in fossil fuel sectors are calibrated to match exogenous estimates of fossil fuel supply elasticities.
14. For example, firms can employ an accountant or a lawyer, or contract for accounting or legal services. They can employ a driver and buy a truck, or contract for delivery services. These examples make it evident that it is more appropriate to allow substitution between business services and primary factors of production than to assume a Leontief structure.
15. Drusilla and Brown (2001) estimate the world-wide cross-border share of trade in services at 41% and the share of trade in services provided by multinational affiliates at 38%. Travel expenditures (20%) and compensation to employees working abroad (1%) make up the difference.
16. The same publication provides information for the year 2000 of oil recovery and mined coal in thousands of tons and on extraction of natural gas (in millions of cubic meters).
17. For the data, see http://sophist.hse.ru/rstat_data/archbase/natur01/1viv1-n/BBF1_10.htm.
18. For multinational shares of services sectors in the ten regions of Russia of our model, we obtain the shares of workers working in multinationals service sectors in each sector from the

Russian government's survey known as the NOBUS survey and combine this with the estimates of the Russian service sector institutes mentioned above. See Rutherford and Tarr (2010) for details.

19. See Böhringer et al. (2014) for a detailed explanation of the data sources and calculation of emissions at the sector and regional level.

20. Non-CO_2 emissions that are not listed at the sector level are assumed to be negligibly small.

21. See Tarr and Volchkova (2013) for details.

22. For more details on the estimation, see Jensen et al. (2007).

23. A 20% CO_2 emission reduction *vis-à-vis* base-year emission levels is roughly in line with the stringency of emission reduction objectives communicated by the Russian government (Ministry of Natural Resources and the Environment of the Russian Federation, 2014).

24. We are precise with cap and trade, but allow for a small tolerance in the solution of up to one percentage point of CO_2 emissions in either emissions intensity or energy intensity standards. That is, CO_2 emissions are reduced by between 19% and 21% with the latter two regulatory policies.

25. Becaue of the possibility of inter-fuel substitution and optimization of export sales in the energy sectors that were not allowed in Rutherford and Tarr (2010), the estimated welfare gains overall are 0.8% of consumption larger with the present model.

26. See Böhringer et al. (2014) for the additional simulations and the multinational investment shares.

27. Antweiler et al. (2001) find small composition effects from trade liberalization because the impacts from the Factor Endowment and Pollution Haven hypotheses tend to offset each other. See also the results of Frankel and Rose (2005) and Dean (2002) for a survey of the trade and environment literature.

28. Martin (2012) econometrically assesses the implications of trade openness on greenhouse gas emissions by India's manufacturing firms. She finds that the reduction in import tariffs led to improved fuel efficiency as fuel efficient manufacturing firms gained market share whereas fuel-inefficient firms lost market share; within the manufacturing sector, improved capital access tended to reduce fuel-intensity rather than increase it because of technological (energy-saving) progress embodied in new vintages.

29. Although our decomposition is based on a methodology that is a local approximation to a discrete change, we find that the sum of our components are accurate to within 0.5 percentage points of CO_2 emissions in all cases except WTO combined with emissions intensity, where the tolerance is 1.2 percentage points of CO_2 emissions.

30. In our dataset, nonferrous metals do not intensively emit CO_2 (see Table 1).

31. An increase in the elasticity of substitution between varieties could reduce the welfare gain. This is because when varieties are good substitutes, additional varieties are worth less to firms and consumers.