Growth and Trade with Frictions: A Structural Estimation Framework*

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October 16, 2016

Abstract

We build and estimate a structural dynamic general equilibrium model of growth and trade. Gravity is combined with a capital accumulation mechanism driving transition between steady states. Trade affects growth through changes in consumer and producer prices that stimulate or impede physical capital accumulation. Simultaneously, growth affects trade, directly through changes in country size and indirectly through changes in the incidence of trade costs. Theory maps to an econometric system that identifies the structural parameters of the model. Counterfactual trade liberalization magnifies static gains on the discounted path to the steady state by a *dynamic path multiplier* of around 1.6.

JEL Classification Codes: F10, F43, O40

Keywords: Trade, Growth, Income, Trade Liberalization, Capital Accumulation.

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Acknowledgements: We thank Costas Arkolakis, Eric Bond, Holger Breinlich, Svetlana Demidova, Klaus Desmet, Jonathan Eaton, Markus Eberhardt, Carsten Eckel, Hartmut Egger, Peter Egger, Giovanni Facchini, Gabriel Felbermayr, Joseph Francois, Gene Grossman, Burkhard Heer, Benedikt Heid, Marten Hillebrand, Richard Hule, Giammario Impullitti, Oleg Itskhoki, Dalia Marin, Xenia Matschke, Thierry Mayer, Daniel Millimet, Eduardo Morales, Julian Emami Namini, Peter Neary, Douglas Nelson, Dennis Novy, Ezra Oberfield, Thomas Osang, Veronica Rappoport, Stephen Redding, Raymond Riezman, Esteban Rossi-Hansberg, Thomas Sampson, Serge Shikher, Michael Sposi, David Stadelmann, Andrey Stoyanov, Costas Syropoulos, Felix Tintelnot, Klaus Wälde, Kei-Mu Yi, and participants at the SIRE Workshop on "Theory and Estimation of Gravity Equations" 2013, Glasgow, the Allied Social Science Associations Annual Meeting 2014, Philadelphia, the Midwest International Economics Group Spring 2014 Meeting, Indianapolis, the SIRE Workshop on "Country Size and Border Effects in a Globalised World" 2014, Edinburgh, the CESifo Workshop on "Regional Mega Deals: New Trends, New Models, New Insights" 2014, Venice, the Conference on Research on Economic Theory and Econometrics 2014, Milos, the 29th Annual Congress of the European Economic Association 2014, Toulouse, the 16th Annual Congress of the European Trade Study Group 2014, Munich, the Annual Meeting of the Society for Economic Dynamics 2015, Warsaw, the "Panel Data Workshop on International Trade", University of Amsterdam 2015, the Annual Congress of the Research Committee on International Economics of the German Economic Society 2015, Tübingen, the CESifo Area Conference on Global Economy 2015, Munich, the XX. Conference on Dynamics, Economic Growth, and International Trade 2015, Geneva, and seminars at Drexel University, Temple University, the Centre for Trade and Economic Integration at the Graduate Institute, Geneva, the Economics Research Institute at the Bulgarian Academy of Sciences, the World Trade Organization, Princeton University, Ludwig-Maximilian University in Munich, University of Bayreuth, McMaster University, York University, the U.S. International Trade Commission, University of Trier, University of Salzburg, CEP/LSE, University of Mainz, the Austrian Institute of Economic Research (WIFO), Vienna, and the Vienna University of Economics and Business for valuable comments and suggestions. Mario Larch is grateful for financial support under the Fritz Thyssen Stiftung grant No. Az. 50.14.0.013.

1 Introduction

The relationship of trade and growth has been a central concern of economists since Adam Smith. More than two centuries later debate continues about an empirically strong relationship between trade and growth.[1] Despite academic doubts, policy analysts and negotiating parties on both sides of trade mega deals such as the Transatlantic Trade and Investment Partnership (TTIP) between the United States and the European Union expect that "TTIP will result in more jobs and growth".[2] These observations motivate our development and estimation of a structural dynamic model of trade and transitional capital accumulation. Accumulation effects are big. Counterfactual simulations of two different trade liberalization experiments with the fitted model yield discounted dynamic gains over the path to the steady state that are more than 60% larger than static gains, a *dynamic path multiplier* around 1.6. Multipliers do not vary much with economy size, in contrast to the static gains that are larger in smaller economies.

The model features many countries that are asymmetric in size, in bilateral trade frictions and in capital accumulation frictions. The CES Armington trade gravity model is combined with a Lucas and Prescott (1971) capital accumulation model of transition between steady states. Two frictions interact on stage: costly trade and costly capital adjustment. Capital stock adjustment in each country is subject to iceberg trade costs because capital requires

[1] In order to motivate their famous paper, Frankel and Romer (1999) note that "[d]espite the great effort that has been devoted to studying the issue, there is little persuasive evidence concerning the effect of trade on income." Similarly, Baldwin (2000) confirms that "[t]he relationships between trade and growth have long been a subject of [study and] controversy among economists. This situation continues today."

Better models could help, but Head and Mayer (2014) note that the best fitting trade model (gravity) is static, and "This raises the econometric problem of how to handle the evolution of trade over time in response to changes in trade costs." (Head and Mayer, 2014, p. 189). Similarly, Desmet and Rossi-Hansberg (2014) note that introducing dynamics to static multi-country trade models adds considerable complexity because: (i) consumers care about the distribution of their economic activities not only over countries, but also over time; and (ii) the clearance of goods and factor markets is difficult, as prices depend on international trade. "These two difficulties typically make spatial dynamic models intractable, both analytically and numerically." (Desmet and Rossi-Hansberg, 2014, p. 1212).

[2] Press release, Brussels, 28 January 2014, http://trade.ec.europa.eu/doclib/press/index.cfm?id=1020. President Obama of U.S. and Minister Rajoy of Spain also agreed that "there is enormous potential for TTIP to increase trade and growth between two of the largest economic actors in the world." (Office of the Press Secretary, White House, January, 2014, http://iipdigital.usembassy.gov/st/english/texttrans/2014/01/20140114290784.html#axzz2u59pirmD.)

imports, but in addition costly adjustment and depreciation act essentially like iceberg frictions on the intertemporal margin. At each point in time bilaterally varying iceberg trade frictions are consistently aggregated into productivity shifters in the form of national multilateral resistances. Over time, the log-linear utility and log-linear capital transition function setup of Lucas and Prescott (1971) and Hercowitz and Sampson (1991) applied here yields a closed-form solution for optimal accumulation by infinitely lived representative agents with perfect foresight.[3] The closed-form solution for accumulation is the bridge to structural estimation of an econometric system of growth and trade.[4]

The estimated model allows quantification of the causal effect of openness on income and growth. It also provides all the key structural parameters needed to simulate counterfactuals with the model.[5] Counterfactual liberalization experiments with the estimated model decompose and quantify the various channels through which trade affects growth and through which growth impacts trade. To compare dynamic gains from liberalization with a static alternative, we follow Lucas (1987) to calculate the constant fraction of aggregate consumption in each year that consumers would need to be paid in the baseline case to give them the same utility they obtain from the consumption stream in the counterfactual.

Our model adds dynamics to the family of new quantitative static trade models, such as Eaton and Kortum (2002) and Anderson and van Wincoop (2003) (as summarized in Costinot and Rodríguez-Clare, 2014).[6] Our model is also related to two notable efforts to

[3]More recently, the log-linear capital transition function was, for example, used by Eckstein et al. (1996) to synthesize exogenous and endogenous sources of economic growth, by Kocherlakota and Yi (1997) to investigate whether permanent changes in government policies have permanent effects on growth rates, and by Abel (2003) to investigate the effects of a baby boom on stock prices and capital accumulation.

[4]In contrast, no closed-form solution is available for models in the spirit of the dynamic, stochastic, general equilibrium (DSGE) open economy macroeconomics literature, such as Backus et al. (1992, 1994). In our robustness analysis (see online Appendix C.3) we experiment with alternative specifications for capital accumulation. While these do not lead to the convenient and tractable closed-form solution from our main analysis, they do generate qualitatively identical and quantitatively similar results.

[5]The internal consistency of parameter estimates with the data basis of counterfactual exercises is a key advantage of our approach: we test for the hypothesized link's significance and use reasonably precise point estimates to quantify the links in simulations. Our system delivers estimates of the trade elasticity, of the capital (labor) share in production, of the capital stock transition parameter, and of bilateral trade costs. The estimates are all comparable to corresponding values from the literature.

[6]In doing so, we extend an earlier literature (i.e., Solow, 1956; Acemoglu and Zilibotti, 2001; Acemoglu and Ventura, 2002; Alvarez and Lucas, Jr., 2007), and we complement some new influential papers (i.e., Sampson,

introduce dynamics within a heterogeneous spatial framework. First, Krusell and Smith, Jr. (1998) show that in macroeconomic models with heterogeneity features, aggregate variables (i.e., consumption, capital stock, and relative prices) can be approximated very well as a function of the mean of the wealth distribution and an aggregate productivity shock. Second, Desmet and Rossi-Hansberg (2014) deliver a tractable dynamic framework, where the firm's dynamic decision to innovate reduces to a sequence of static profit-maximization problems, by imposing structure that disciplines the mobility of labor, land-ownership by the firm, and the diffusion of technology.[7]

An important difference between these models and ours is that the models of Krusell and Smith, Jr. (1998) and Desmet and Rossi-Hansberg (2014) are stochastic whereas ours is deterministic. Without stochastic shocks, our optimization problem boils down to solving a non-linear equation system between the steady states. Similar to Desmet and Rossi-Hansberg (2014), we offer an analytical solution to the consumer's dynamic decision to invest. Added tractability comes from gravity structure that consistently aggregates bilateral trade frictions for each country into multilateral resistance indexes. This second feature is similar to Krusell and Smith, Jr. (1998), but replaces an approximation with an exact ideal index based on the structure of the system.

We abstract from non-zero steady-state growth for simplicity.[8] We also abstract from endogenous technological change, but changes in multilateral resistance are effectively a type of endogenous technological change.

2016; Eaton et al., 2016) that study the dynamics of trade. These studies calibrate their models in arguably more complex environments. In contrast, we deliver a structural econometric system that allows us to test and establish causal relationships between trade, income, and growth and delivers the key parameters that we employ in our counterfactual analysis. The price of this estimatability is a focus on capital accumulation as the single channel for transmitting dynamic effects along with convenient functional form assumptions.

[7]The usefulness of this approach is shown by Desmet and Rossi-Hansberg (2015) who apply it to study the geographic impact of climate change, and Desmet et al. (2016) who develop a dynamic spatial growth theory with realistic geography to study the effects of migration and of a rise in the sea level.

[8]Growth in our framework is exclusively driven by capital accumulation. Please see the literature review Section 2 for motivation of this choice. Further, consistent with the description of the role of capital accumulation in transitional dynamics in Grossman and Helpman (1991), our framework generates transitional but not steady-state growth. Thus, if not mentioned explicitly otherwise, when we use the term "growth" we have in mind capital accumulation between steady states.

The structural gravity setup of Anderson and van Wincoop (2003) based on constant elasticity of substitution (CES) preferences over products differentiated by place of origin (Armington, 1969) forms the trade module of the model.[9] Recent work by Arkolakis et al. (2012, henceforth also ACR) argues that gains from trade measures in such models represent a general class of models for which the key parameter is a single trade elasticity. This class of models readily integrates with our model of capital accumulation. Capital itself is an alternative use of the consumable bundle. In the steady state, the accumulation flow offsets depreciation, essentially equivalent to a composite intermediate good. In this sense the model is isomorphic to Eaton and Kortum (2002) but with substitution on the intensive margin. An extension to incorporate intermediate goods following Eaton and Kortum (2002) confirms that qualitative properties are the same while quantitative results shift significantly.

We implement the dynamic structural gravity model on a sample of 82 countries over the period 1990–2011. First, we translate the model into a structural econometric system that offers a theoretical foundation to and expands the famous reduced-form specification of Frankel and Romer (1999). In addition, we complement Frankel and Romer (1999) and a series of other studies by proposing three novel instruments derived from structural gravity to identify the effects of trade openness on income.[10] Similar to Frankel and Romer (1999) and other related studies, we identify a significant causal effect of trade on income. In addition, we

[9]The gravity model is the workhorse in international trade. Anderson (1979) is the first to build a gravity theory of trade based on CES preferences with products differentiated by place of origin. Bergstrand (1985) embeds this setup in a monopolistic competition framework. More recently, Eaton and Kortum (2002), Helpman et al. (2008), and Chaney (2008) derived structural gravity based on selection (hence substitution on the extensive margin) in a Ricardian framework. Costinot et al. (2012) and Caliendo and Parro (2015) build on Eaton and Kortum (2002) to offer solid theoretical foundations for empirical gravity analysis in a multi-sector Ricardian setting and a multi-sector setting with intermediates, respectively. As noted by Eaton and Kortum (2002) and Arkolakis et al. (2012), a large class of models generate isomorphic gravity equations. Anderson (2011) and Costinot and Rodríguez-Clare (2014) summarize the alternative theoretical foundations of economic gravity.

[10]Notable studies that propose alternative instruments for trade/trade openness in Frankel-Romer settings include Redding and Venables (2004), that uses a version of their market access index, Feyrer (2009b), that proposes a new time-varying geographic instrument which capitalizes on the fact that country pairs with relatively short air routes have benefited more from improvements in technology, Feyrer (2009a), that exploits the closing of the Suez canal as a natural experiment, Lin and Sim (2013), that constructs a new measure of trade cost based on the Baltic Dry Index, and Felbermayr and Gröschl (2013), that uses natural disasters as an instrument. See Sections 4.1.2 and 4.3.2 for further details and performance of our instrument.

complement the trade-and-income system of Frankel and Romer with a structural equation that captures the effects of trade openness on capital accumulation. The estimation of our structural system yields estimates of all but one of the model parameters.

Two counterfactual liberalization experiments quantify and decompose the relationships between growth and trade, each based on the newly constructed trade costs combined with data on the rest of the variables in our model. These experiments reveal that the dynamic effects of trade liberalization lead to an over 60 percent increase in the corresponding static effects, implying a *dynamic path multiplier* of around 1.6.

In the first experiment we find that the average welfare for the North American Free Trade Agreement (NAFTA) members increases from 1.27% to 2.06%. Following Estevadeordal and Taylor (2013), we calculate a yearly growth rate effect of NAFTA for the first 15 years of adjustment of about 0.116%, while for the non-NAFTA countries we find a small negative effect of −0.001%. Hence, our framework implies an acceleration in growth rates of real gross domestic product (GDP) in NAFTA countries compared to non-NAFTA countries of about 0.117% per year for the first 15 years after the implementation of NAFTA.[11] The second, *'globalization'*, experiment examines the effect of a *uniform* fall in international trade costs of 6.4%. All countries gain, smaller ones gain more, and the *dynamic path multiplier* is around 1.6 for all countries despite the big differences in size.

We view the simplicity, tractability, ability to test for key causal relationships and to estimate all structural parameters within the same model as important advantages of our dynamic structural estimating gravity framework. These benefits come at the cost of some important abstractions. We devoted significant effort to accommodate and discuss the implications of a series of potential improvements and generalizations that have been proposed in

[11] Estevadeordal and Taylor (2013) use a small open developing economy model to motivate their empirical difference equation. They use a treatment-and-control approach to compare the acceleration in growth rates of real GDP in liberalizing countries compared to non-liberalizing countries. The main finding is a difference in the two groups' trends of about 1% per year. Our comparable finding of 0.12% is based on a structural model taking care of all general equilibrium effects which is not possible with a treatment-and-control approach and potentially biasing the results substantially (see Heckman and Taber, 1998). Sampson (2016) finds in a setting with heterogeneous firms that the dynamic effects of trade liberalization triple.

the related literature including: alternative specifications for capital accumulation (in online Appendix K); allowing for intermediate goods (in online Appendix L); deriving the model with an iso-elastic utility function (in online Appendix M); deriving an ACR-type formula in steady state (in online Appendix E.1) and out-of steady state (in online Appendix E.2); solving our dynamic system of growth-and-trade in changes (in online Appendix H); and checking the robustness of our results to alternative values for all structural parameters (in online Appendix C).

Other difficult but important extensions include the development of a dynamic multi-sector framework (with no-traded goods) in the spirit of Costinot et al. (2012); allowing for international lending or borrowing, following Eaton et al. (2016); incorporating foreign direct investment, and modeling labor markets.[12] We leave these extensions for future research.

The rest of the paper is organized as follows. In section 2 we present our contributions in relation to existing studies. Section 3 develops the theoretical foundation and discusses the structural links between growth and trade in our model. In Section 4, we translate our theoretical framework into an econometric model. Section 5 offers counterfactual experiments. Section 6 concludes with some suggestions for future research. All derivations, technical discussions and robustness experiments can be found in the online Appendix.

2 Relation to Literature

Our work contributes to several influential strands of the literature. First, we build a bridge between the empirical and theoretical literature on the links between growth and trade. The seminal work of Frankel and Romer (1999) uses a reduced-form framework to study the relationships between income and trade.[13] Wacziarg (2001) investigates the links between trade policy and economic growth employing a panel of 57 countries for the period of 1970

[12]Extending our framework to accommodate these forces while preserving the closed-form solution for accumulation may be challenging but feasible because either relaxation implies a contemporaneous allocation of investment across sectors and/or countries with an equilibrium that can nest in the intertemporal allocation of the dynamic model.

[13]In order to account for the endogeneity problems that plague the relationships between income and trade, Frankel and Romer (1999) draw from the early, a-theoretical gravity literature (see Tinbergen, 1962) and propose to instrument for trade flows with geographical characteristics and country size.

to 1989. A key finding is that physical capital accumulation accounts for about 60% of the total positive impact of openness on economic growth. Baldwin and Seghezza (2008) and Wacziarg and Welch (2008) confirm these findings for up to 39 countries for two years (1965 and 1989) and a set of 118 countries over the period 1950 to 1998, respectively. Cuñat and Maffezzoli (2007) demonstrate the role of factor accumulation to reproduce the large observed increases in trade shares after modest tariff reductions.

More recently, Eaton et al. (2016) find that "[...] a decline in the efficiency of investment in durable manufacturing capital stocks drove the stunning collapse in trade and in manufacturing production that accompanied the global recession." (p. 32). Egger and Nigai (2016) undertook a trade-growth accounting exercise and found that "[o]verall, the preferable dynamic, endogenous-endowments-and-technology model suggested that (shocks to) endowment accumulation, trade costs, and productivity—in that order—were the most important drivers of world trade between 1988 and 2007." (p. 29).

These studies motivate our focus on capital accumulation as the source of growth in our model.[14] We extend this literature in three ways. First, we offer a theoretical equation that corresponds directly to the reduced-form specification of Frankel and Romer (1999). Second, we propose three novel instruments for trade openness derived from estimated structural gravity. Third, we introduce a theoretically-motivated equation that captures the effects of trade on capital accumulation and hence growth.

On the structural trade-and-growth side, our paper is related to a series of influential papers by Jonathan Eaton and Samuel Kortum (see Eaton and Kortum, 2001, 2002, 2005),[15] who study the links between trade, production and growth via technological spill-overs.

[14] The correlation in our sample between changes in trade openness (measured as exports plus imports as share of gross domestic product) and changes in capital accumulation is about 0.38 (p-value 0.002).

[15] The work of Eaton and Kortum that is most closely related to our study is thoroughly summarized in their manuscript Eaton and Kortum (2005). Most relevant to our work are their chapters ten and eleven, which study how trade in capital goods possibly transmits technological advances and investigate the geographical scope of technological progress in a multi-country (semi)endogenous growth framework, respectively. For a thorough review of the earlier theoretical literature on trade and (endogenous) technology, we refer the reader to Grossman and Helpman (1995). More recent developments include Acemoglu and Zilibotti (2001), Acemoglu and Ventura (2002), Alvarez and Lucas, Jr. (2007), Sampson (2016), and Eaton et al. (2016).

We abstract from the random productivity draws setup of Eaton and Kortum (EK) for simplicity, since the EK model is observationally equivalent to the structural gravity model we estimate. This simplicity allows our addition of capital accumulation in transition. The steady state of our model is equivalent to EK if we add a flow use of intermediate goods to the flow of capital to offset depreciation. While the relationships between growth and trade are of central interest in this paper and in Eaton and Kortum's work, we view our study as complementary to Eaton and Kortum's agenda because the dynamic relationships between trade and production in our model are generated via capital accumulation.[16]

Our approach is related to recent influential work by Eaton et al. (2016), EKNR hereafter. We share with EKNR the common elements of a gravity structure and capital accumulation specified as a perfect foresight Cobb-Douglas adjustment process as in Lucas and Prescott (1971). We differ in imposing the polar case of financial autarky in contrast to the complete markets polar case of EKNR and, less essentially, in assuming one good in contrast to the four goods of EKNR. Our strategy of simplification attains an estimatable system focused on the contribution of transitional growth on a trend line of trade policy. EKNR focus on a real business cycle decomposition of the sources of the Great Recession trade collapse, where key parameter values are assumed and trade friction and investment efficiency shocks are inferred using the "wedges" technique of Chari et al. (2007). Another difference is that EKNR's sectoral setting allows for the capturing of structural changes in response to trade liberalization while our framework is aggregate. Our approach is suited to thinking about the impact of a trade policy shift such as a big regional trade agreement starting in the neighborhood of an economy-wide steady state, using estimated parameters that best fit the model to the panel data of that steady state for the countries and years chosen.

Our model is also related to Acemoglu and Ventura (2002), who develop an AK-model with trade in intermediates and without capital depreciation in continuous time to show

[16] Even though technology is exogenous in our model, our framework has implications for TFP calculations and estimations. In particular, the introduction of a structural trade costs term in the production function reveals potential biases in the existing estimates of technology. In addition, our model can be used to simulate the effects of exogenous technological changes.

that even without diminishing returns in production of capital, international trade leads to a stable world income distribution due to terms-of-trade adjustments. Note that in Acemoglu and Ventura (2002) the optimal policy is "...to consume a fixed fraction of wealth." (p. 667). This is similar to our optimal policy rule in the case of a log-linear intertemporal utility function and a log-linear capital transition function. Besides the differences in the model structure (continuous time, trade in intermediates, no capital depreciation, and no diminishing returns to capital), the focus of Acemoglu and Ventura (2002) is to provide a framework with a stable world income distribution in an AK-setting. Our goal is to develop an estimable dynamic gravity framework suitable for ex-post and ex-ante policy evaluation.

From a modeling perspective, the model in the main part of our paper (with Cobb-Douglas capital accumulation) can be viewed as a Solow model because, as in Solow, consumption and investment are constant shares of real GDP in our setting with the log-linear capital accumulation function. However, there are two important differences. The first difference is that, in our case, the investment/consumption share is not just a single exogenously given parameter, but it rather consists of a combination of several structural parameters in the model. The second difference is that once we use linear capital accumulation (in our robustness analysis), we depart further from Solow as consumption and expenditure are no longer constant shares of real GDP, even with a log-linear intertemporal utility function.

We also contribute to the literature on the effects of RTAs with a framework to study their *dynamic* effects. Two results stand out. First, we find that the dynamic effects of RTAs are strong for member countries and relatively week for outsiders. Second, our NAFTA counterfactual experiment reveals the possibility for non-monotonic effects of preferential trade liberalization on non-member countries. As discussed earlier, the reason is a combination of the trade-driven growth of member countries and the fact that the falling incidence of trade costs for the producers in the growing member economies is shared with buyers in outside countries. These findings offer encouraging support in favor of ongoing trade liberalization and integration efforts.

A useful by-product of our model is a direct estimate of the trade elasticity, which has gained recent popularity as the single most important trade parameter (see ACR). The estimator is due to a structural trade term in the production function of our model and the fact that the trade elasticity is related to the elasticity of substitution σ by $1-\sigma$. With values of the elasticity of substitution between 4.1 and 11.3 (implying trade elasticities between -10.3 and -3.1) from alternative specifications and robustness experiments, our estimates of the elasticity of substitution are comparable to the ones from the existing literature, which usually vary between 2 and 12.[17] In the sensitivity experiments, we checked the robustness of our results using different values for the elasticity of substitution.

Finally, in broader context, using the gravity model as a vehicle to study the empirical relationships between growth and trade is pointed as an important direction for future research by Head and Mayer (2014). On the theoretical side, we extend the family of static gravity models (see footnote 9) by a structural dynamic model of trade, production and growth. On the empirical side, we build on leading static empirical gravity frameworks, e.g. Waugh (2010), that investigates the role of asymmetric trade costs for differences in standards of living and total factor productivity across countries, and Redding and Venables (2004), who structurally estimate a new economic geography model to evaluate the cross-country differences in income per capita and manufacturing wages, and we complement Olivero and Yotov (2012) and Campbell (2010), who build estimating dynamic gravity equations, by testing and establishing the causal relationships between trade, income, and growth.[18]

[17] See Eaton and Kortum (2002), Anderson and van Wincoop (2003), Broda et al. (2006) and Simonovska and Waugh (2014). Costinot and Rodríguez-Clare (2014) and Head and Mayer (2014) each offer a summary and discussion of the available methods to obtain estimates of the elasticity of substitution and trade elasticity parameters. For example, a value for the elasticity of substitution can be obtained by employing bilateral tariff data. Our structural model is compatible with and can incorporate (conditional on data availability) these methods to recover the elasticity of substitution.

[18] There is also a literature that explains export dynamics (see for example Das et al., 2007; Morales et al., 2015) and one that focuses on adjustment dynamics and business cycle effects of trade liberalization (see for example Artuç et al., 2010; Cacciatore, 2014; Dix-Carneiro, 2014). Export dynamics and adjustment and business cycle dynamics are beyond the scope of this paper.

3 Theoretical Foundation

The theoretical foundation used here to quantify the relationships between growth and trade combines the static structural trade gravity setup of Anderson and van Wincoop (2003) with dynamically endogenous production and capital accumulation in the spirit of the models developed by Lucas and Prescott (1971) and Hercowitz and Sampson (1991). Goods are differentiated by place of origin and each of the N countries in the world is specialized in the production of a single good j. Total nominal output in country j at time t ($Y_{j,t}$) is produced subject to the following constant returns to scale (CRS) Cobb-Douglas production function:

$$Y_{j,t} = p_{j,t}A_{j,t}L_{j,t}^{1-\alpha}K_{j,t}^{\alpha} \quad \alpha \in (0,1), \tag{1}$$

where $p_{j,t}$ denotes the factory-gate price of good (country) j at time t and $A_{j,t}$ denotes technology in country j at time t. $L_{j,t}$ is the inelastically supplied amount of labor in country j at time t and $K_{j,t}$ is the stock of capital in j at t. Capital and labor are country-specific (internationally immobile), and capital accumulates according to:

$$K_{j,t+1} = \Omega_{j,t}^{\delta}K_{j,t}^{1-\delta}, \tag{2}$$

where $\Omega_{j,t}$ denotes the flow of investment in j at time t and $\delta \in (0,1]$ is the *capital stock transition parameter*.[19] Transition function (2) combines depreciation of old capital with costs of adjustment in embodying investment into new capital.[20]

Representative agents in each country work, invest and consume. Consumer preferences are identical and represented by a logarithmic utility function with a subjective discount factor $\beta \in (0,1)$. At every point in time consumers in country j choose aggregate consumption ($C_{j,t}$) and aggregate investment ($\Omega_{j,t}$) to maximize the present discounted value of lifetime

[19] This term is apt, but there appears to be no standard term for δ in the literature.

[20] Alternatively, one could view (2) as incorporating diminishing returns in research activity or as quality differences between old capital as compared to new investment goods. Note that this formulation does not allow for zero investment $\Omega_{j,t}$ in any period. Further, in the long-run steady-state, the transition function implies full depreciation. Despite these limitations, we prefer this function over the more standard linear capital accumulation function for our main analysis. The benefits are: (i) a tractable closed-form solution of our model; and (ii) a self-sufficient structural system that can be estimated. In online Appendices K and C.3, respectively, we re-derive our model and we perform sensitivity experiments with a linear capital accumulation function. Even though this function no longer allows for a closed-form solution and requires the use of external calibrated parameters, we do find qualitatively identical and quantitatively similar results.

utility subject to a sequence of constraints:

$$
\begin{aligned}
\max_{\{C_{j,t},\Omega_{j,t}\}} \quad & \sum_{t=0}^{\infty} \beta^t \ln(C_{j,t}) && (3)\\
K_{j,t+1} &= \Omega_{j,t}^{\delta} K_{j,t}^{1-\delta}, \ \forall t && (4)\\
Y_{j,t} &= p_{j,t} A_{j,t} L_{j,t}^{1-\alpha} K_{j,t}^{\alpha}, \ \forall t && (5)\\
E_{j,t} &= P_{j,t} C_{j,t} + P_{j,t} \Omega_{j,t}, \ \forall t && (6)\\
E_{j,t} &= \phi_{j,t} Y_{j,t}, \ \forall t && (7)\\
K_{j,0} \quad & \text{given.} && (8)
\end{aligned}
$$

Equations (4) and (5) define the law of motion for the capital stock and the value of production, respectively. The budget constraint (6) states that aggregate spending in country j, $E_{j,t}$, has to equal the sum of spending on both consumption and investment goods. Equation (7) relates aggregate spending to the value of production by allowing for exogenous trade imbalances, expressed as a factor of the value of production $\phi_{j,t} > 0$. Aggregate consumption and investment are both comprised by domestic and foreign goods, $c_{ij,t}$ and $I_{ij,t}$:

$$C_{j,t} = \left(\sum_i \gamma_i^{\frac{1-\sigma}{\sigma}} c_{ij,t}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \tag{9}$$

$$\Omega_{j,t} = \left(\sum_i \gamma_i^{\frac{1-\sigma}{\sigma}} I_{ij,t}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}. \tag{10}$$

Equation (9) defines the consumption aggregate ($C_{j,t}$) as a function of consumption from each region i ($c_{ij,t}$), where γ_i is a positive distribution parameter, and $\sigma > 1$ is the elasticity of substitution across goods varieties from different countries. Equation (10) presents a CES investment aggregator ($\Omega_{j,t}$) that describes investment in each country j as a function of domestic components ($I_{jj,t}$) and imported components from all other regions $i \neq j$ ($I_{ij,t}$).[21]

[21] The assumption that consumption and investment goods are both a combination of all world varieties subject to the same CES aggregation is very convenient analytically. In addition, it is also consistent with our aggregate approach in this paper. Allowing for heterogeneity in preferences and prices between and within consumption and investment goods will open additional channels for the interaction between trade and growth which require sectoral treatment. This is beyond the scope of this paper, and we refer the reader to Osang and Turnovsky (2000), Mutreja et al. (2014), and Eaton et al. (2016) for efforts in that direction.

Let $p_{ij,t} = p_{i,t}t_{ij,t}$ denote the price of country i goods for country j consumers, where $t_{ij,t}$ is the variable bilateral trade cost factor on shipment of commodities from i to j at time t. Technologically, a unit of distribution services required to ship goods uses resources in the same proportions as does production. The units of distribution services required on each link vary bilaterally. Trade costs can be interpreted by the standard iceberg melting metaphor; it is as if goods melt away so that 1 unit shipped becomes $1/t_{ij,t} < 1$ units on arrival.

System (3)-(8) decomposes into a nested two-level optimization problem. The lower level problem obtains the optimal demand of $c_{ij,t}$ and $I_{ij,t}$, for given $C_{j,t}$, $\Omega_{j,t}$, and $Y_{j,t}$. The upper level dynamic optimization problem solves for the optimal sequence of $C_{j,t}$ and $\Omega_{j,t}$. Consider the lower level first. Let $X_{ij,t}$ denote country j's total nominal spending on goods from country i at time t. The agents' optimization of (9)-(10), subject to $E_{j,t} = \phi_{j,t}Y_{j,t} = \sum_i X_{ij,t} = \sum_i p_{ij,t}(c_{ij,t} + I_{ij,t})$, taking $C_{j,t}$ and $\Omega_{j,t}$ as given, and using (6) yields:

$$X_{ij,t} = \left(\frac{\gamma_i p_{i,t} t_{ij,t}}{P_{j,t}}\right)^{1-\sigma} E_{j,t}, \tag{11}$$

where $P_{j,t} = \left[\sum_i (\gamma_i p_{i,t} t_{ij,t})^{1-\sigma}\right]^{1/(1-\sigma)}$ is the CES price aggregator index for country j at time t. Note that equation (11) implies that the partial elasticity of relative imports $(X_{ij,t}/X_{jj,t})$ with respect to variable trade costs, referred to as "trade elasticity" (see Arkolakis et al., 2012), is given by $(1-\sigma)$. Market clearance, $Y_{i,t} = \sum_j X_{ij,t}$, implies:

$$Y_{i,t} = \sum_j (\gamma_i p_{i,t})^{1-\sigma} (t_{ij,t}/P_{j,t})^{1-\sigma} E_{j,t}. \tag{12}$$

(12) simply tells us that, at delivered prices, the output in each country should equal total expenditures on this nation's goods in the world, including i itself. Define $Y_t \equiv \sum_i Y_{i,t}$ and divide the preceding equation by Y_t to obtain:

$$(\gamma_i p_{i,t} \Pi_{i,t})^{1-\sigma} = Y_{i,t}/Y_t, \tag{13}$$

where $\Pi_{i,t} \equiv \left[\sum_j \left(\frac{t_{ij,t}}{P_{j,t}}\right)^{1-\sigma} \frac{E_{j,t}}{Y_t}\right]^{1/(1-\sigma)}$. Using (13) to substitute for the power transform of factory-gate prices, $(\gamma_i p_{i,t})^{1-\sigma}$ in equation (11) above and in the CES consumer price aggregator following (11), delivers the gravity system of Anderson and van Wincoop (2003):

$$X_{ij,t} = \frac{Y_{i,t}E_{j,t}}{Y_t}\left(\frac{t_{ij,t}}{\Pi_{i,t}P_{j,t}}\right)^{1-\sigma}, \tag{14}$$

$$P_{j,t} = \left[\sum_i \left(\frac{t_{ij,t}}{\Pi_{i,t}}\right)^{1-\sigma}\frac{Y_{i,t}}{Y_t}\right]^{\frac{1}{1-\sigma}}, \qquad \Pi_{i,t} = \left[\sum_j \left(\frac{t_{ij,t}}{P_{j,t}}\right)^{1-\sigma}\frac{E_{j,t}}{Y_t}\right]^{\frac{1}{1-\sigma}}. \tag{15}$$

Equation (14) intuitively links bilateral exports to market size (the first term on the right-hand side) and trade frictions (the second term on the right-hand side). Coined by Anderson and van Wincoop (2003), $\Pi_{i,t}$ and $P_{j,t}$ are the multilateral resistance terms (MRs, outward and inward, respectively), which consistently aggregate bilateral trade costs and decompose their incidence on the producers and the consumers in each region (Anderson and Yotov, 2010). The multilateral resistances are key to our analysis because they represent the endogenous structural link between the lower level trade analysis and the upper level production and growth equilibrium. The MRs translate changes in bilateral trade costs at the lower level into changes in factory-gate prices, which stimulate or discourage investment and growth at the upper level. At the same time, by changing output shares in the multilateral resistances, capital accumulation and growth alter the incidence of trade costs in the world.

The upper level dynamic optimization problem solves for sequence $\{C_{j,t}, \Omega_{j,t}\}$. As discussed in Heer and Maußner (2009, chapter 1), this specific set-up with logarithmic utility and log-linear adjustment costs has the advantage of delivering an analytical solution. The solution for the policy function of capital is given by (see for details online Appendix A):

$$K_{j,t+1} = \left[\frac{\alpha\beta\delta\phi_{j,t}p_{j,t}A_{j,t}L_{j,t}^{1-\alpha}}{(1-\beta+\beta\delta)\,P_{j,t}}\right]^{\delta} K_{j,t}^{\alpha\delta+1-\delta}. \tag{16}$$

Policy function (16) is consistent with infinitely forward looking agents despite the appearance of one period ahead prices only. This is due to the log-linear functional form of both preferences and capital accumulation, implying that marginal rates of substitution are proportional to the ratio of present to one-period-ahead consumption or capital stocks.[22]

[22] In online Appendix B we confirm that our results are replicated by the standard dynamic solution method using Dynare (Adjemian et al., 2011, http://www.dynare.org/). Thus, we solve our models in two completely different ways leading to exactly the same results: i) we use our analytically derived policy function and solve the transition by starting from the baseline steady state and solving for subsequent periods until convergence

As expected, (16) depicts the direct relationship between capital stock in period $t+1$ and the levels of technology $A_{j,t}$, labor endowment $L_{j,t}$, and current capital stock $K_{j,t}$. More important for the purposes of this paper, (16) suggests a direct relationship between capital accumulation and the prices of domestically produced goods and an inverse relationship between capital accumulation and the aggregate consumer price index $P_{j,t}$.[23] The intuition behind the positive relationship between the prices of domestic goods and capital accumulation is that, all else equal, when faced with higher returns to investment given by the value marginal product of capital $\alpha p_{j,t} A_{j,t} L_{j,t}^{1-\alpha} K_{j,t}^{\alpha-1}$, consumers invest more. The intuition behind the negative relationship between capital accumulation and aggregate consumer prices is that an increase in $P_{j,t}$ means that consumption as well as investment become more expensive. This reduces the incentive to build up capital.

The relationships between prices and capital accumulation are crucial for understanding the relationships between growth and trade. Changes in trade costs will result in changes in international prices, which will affect capital accumulation. Specifically, the inward multilateral resistance from equation (15) consistently aggregates the changes in bilateral trade costs between any pair of countries in the world for a given economy. Thus, if a country liberalizes, its inward MR falls and this triggers investment. However, if liberalization takes place in the rest of the world, this will result in an increase in the MRs for outsiders, and therefore lower investment. Equation (16) reveals a direct relationship between factory-gate prices and investment. Similar to the inward MRs, factory-gate prices consistently aggregate the effects of changes in bilateral trade costs in the world on investment decisions in a given country. The intuition is that when a country opens to trade, producers in this country enjoy lower outward MR, which, according to equation (13), translates into higher factory-gate prices. Outsiders face higher outward MR, their factory-gate prices fall, and investment falls.

to the counterfactual steady state. ii) we use the first-order conditions and solve our non-linear equation system using Dynare. We also use Dynare to solve our model when we employ the linear capital accumulation function as a robustness check in online Appendix C.3.

[23]The price of domestic goods enters the aggregate price index and, via this channel, it has a negative effect on capital accumulation. However, as long as country j consumes at least some foreign goods, this negative effect will be dominated by the direct positive effect of domestic prices on capital accumulation.

Given the policy function for capital, we can easily calculate investment, $\Omega_{j,t}$, consumption, $C_{j,t}$, and aggregate spending, respectively, as (see for details online Appendix A):

$$\Omega_{j,t} = \left[\frac{\phi_{j,t} p_{j,t} A_{j,t} L_{j,t}^{1-\alpha} \alpha\beta\delta}{P_{j,t}(1-\beta+\beta\delta)}\right] K_{j,t}^{\alpha} = \left[\frac{\alpha\beta\delta}{1-\beta+\beta\delta}\right] \frac{E_{j,t}}{P_{j,t}}, \tag{17}$$

$$C_{j,t} = \left[\frac{1-\beta+\beta\delta-\alpha\beta\delta}{1-\beta+\beta\delta}\right] \frac{\phi_{j,t} p_{j,t} A_{j,t} L_{j,t}^{1-\alpha} K_{j,t}^{\alpha}}{P_{j,t}} = \left[\frac{1-\beta+\beta\delta-\alpha\beta\delta}{1-\beta+\beta\delta}\right] \frac{E_{j,t}}{P_{j,t}}, \tag{18}$$

$$E_{j,t} = \phi_{j,t} Y_{j,t} = \phi_{j,t} p_{j,t} A_{j,t} L_{j,t}^{1-\alpha} K_{j,t}^{\alpha}. \tag{19}$$

System (17)-(19) reveals that aggregate consumption and aggregate investment at the upper level are linked to the lower level via the general equilibrium consumer price indexes and factory-gate prices. In addition, the right-hand side expressions in the first two equations reveal that investment and consumption in each period are always a constant fraction of real aggregate spending. This is due to the log-linear functional form of capital accumulation that enables us to obtain an analytical solution for the capital policy function.[24] Note that when there are no costs in adjustment of the volume of capital, i.e., $\delta = 1$, (16)-(19) implies that adjustment to the steady state is instantaneous. Thus adjustment costs for capital play the same role in capital adjustment (17) as iceberg costs play in gravity equation (14).[25]

The combination of the lower level gravity system (14)-(15), the market clearing conditions (13), the policy function for capital (16), as well as the definition of nominal output (1) delivers our theoretical model of growth and trade:

[24] The intuition is that given real aggregate spending at point t, the optimal distribution of expenditure on investment and consumption in t is a constant share, irrespective of what will happen in the future.

[25] In the special case where the trade costs reflect home bias in preferences, the similarity is even closer.

$$
\begin{aligned}
X_{ij,t} &= \frac{Y_{i,t}\phi_{j,t}Y_{j,t}}{Y_t}\left(\frac{t_{ij,t}}{\Pi_{i,t}P_{j,t}}\right)^{1-\sigma}, && (20)\\
P_{j,t} &= \left[\sum_i \left(\frac{t_{ij,t}}{\Pi_{i,t}}\right)^{1-\sigma}\frac{Y_{i,t}}{Y_t}\right]^{\frac{1}{1-\sigma}}, && (21)\\
\Pi_{i,t} &= \left[\sum_j \left(\frac{t_{ij,t}}{P_{j,t}}\right)^{1-\sigma}\frac{\phi_{j,t}Y_{j,t}}{Y_t}\right]^{\frac{1}{1-\sigma}}, && (22)\\
p_{j,t} &= \frac{(Y_{j,t}/Y_t)^{\frac{1}{1-\sigma}}}{\gamma_j\Pi_{j,t}}, && (23)\\
Y_{j,t} &= p_{j,t}A_{j,t}L_{j,t}^{1-\alpha}K_{j,t}^{\alpha}, && (24)\\
K_{j,t+1} &= \left[\frac{\alpha\beta\delta\phi_{j,t}p_{j,t}A_{j,t}L_{j,t}^{1-\alpha}}{(1-\beta+\beta\delta)P_{j,t}}\right]^{\delta}K_{j,t}^{\alpha\delta+1-\delta}, && (25)\\
K_{j,0} &\quad \text{given.}
\end{aligned}
$$

The beauty of system (20)-(25) is that the universe of bilateral trade linkages are consistently aggregated for each country and they are nested in the upper level capital accumulation framework via the MRs.[26] Our strategy in the subsequent sections is to translate system (20)-(25) into an econometric model, which we estimate in order test and establish the causal relationships between trade, income and growth and to recover the structural parameters of the model, which are needed to perform our counterfactual experiments. Before that, however, we discuss the structural effects of trade on growth that our model offers.

3.1 Growth and Trade: A Discussion

Trade's effect on growth acts in the model through a relative price channel. Trade cost changes shift producer prices relative to consumer prices. More subtly, when trade is costly, trade volume changes also induce shifts in producer relative to consumer prices. Shifts in relative prices affect accumulation, and accumulation affects next period trade. Higher

[26] (20)-(25) is a well-behaved dynamic problem. We show in Section A.2 that the following transversality condition always holds: $\lim_{t\to\infty}\beta^t\frac{\partial F(K^*_{j,t},K^*_{j,t+1})}{\partial K_{j,t}}K^*_{j,t} = 0$, where $F \equiv \ln\left[\left(\phi_{j,t}p_{j,t}A_{j,t}L_{j,t}^{1-\alpha}K_{j,t}^{\alpha}\right)/P_{j,t} - \left(K_{j,t+1}/K_{j,t}^{1-\delta}\right)^{1/\delta}\right]$, and stars denote the solutions of the dynamic problem. With the given parameter restrictions on α, β, and δ, the solution for the endogenous variables of system (20)-(25) can be shown to be unique. This is demonstrated in Allen et al. (2014), and more specifically in the accompanying note, "Capital Dynamics", which covers our case.

producer prices increase accumulation because they imply higher returns to investment. Higher investment and consumer prices, in contrast, reduce accumulation due to higher costs of investment and due to higher opportunity costs of consumption. Importantly, due to the general equilibrium forces in our model, changes in trade costs or trade volumes between any two trading partners potentially affect producer prices and consumer prices in any nation in the world. In the empirical results, such third-party effects are significant.

Growth affects trade via two channels, direct and indirect. The direct effect of growth on trade is strictly positive, acting through country size. Growth in one economy results in more exports and in more imports with all of its trading partners. The indirect effect of growth on trade arises because changes in country size translate into changes in the multilateral resistance for all countries, with knock on changes in trade flows. Importantly, the indirect channel through which growth affects trade is also a general equilibrium one, i.e., growth in one country affects trade costs and impacts welfare in every other country in the world. Work done on other data (e.g. Anderson and Yotov, 2010; Anderson and van Wincoop, 2003) reveals that a higher income is strongly associated with lower sellers' incidence of trade costs and thus a real income increase, a correlation replicated here. Closing the loop, growth-led changes in the incidence of trade costs leads to additional changes in capital stock.

The dynamic feature of our model allows quantification of the intuition that preferential trade liberalization (e.g. a RTA) may benefit non-members through the growth of members and the resultant terms of trade improvement of non-members. By making investment more attractive, a RTA will stimulate growth in the member countries. This will lead to lower sellers' incidence for these countries, but also to lower buyers' incidence in non-members. The latter complements the direct positive size effect of member countries on non-member exports that we described above.[27]

[27] Theory reveals that, in principle, growth due to regional trade liberalization can lead to benefits for outside countries that do not participate in the integration effort. Such effects cannot be observed in an aggregate setting such as ours, but are more likely to arise within a multi-sector framework where growth leads to specialization. It should also be noted, however, that even though we do not observe positive welfare effects for outside countries in our sample, we do find non-monotonic trade diversion effects. In some cases (e.g. Austria), the dynamic forces in our framework lead to trade creation effects that are stronger than the

The long-run effects of trade costs on growth are captured by the comparative statics of the steady states. Steady-state capital is $K_j = (\alpha\beta\delta\phi_j Y_j)/[(1-\beta+\beta\delta)P_j]$. The ratio of steady-state capital stocks between the counterfactual steady state, K_j^c, and the baseline steady state, K_j^b, can be expressed as (see online Appendix D for a detailed derivation): $\widehat{K}_j = K_j^c/K_j^b = \widehat{P}_j^{\frac{-\sigma}{\sigma(1-\alpha)+\alpha}} \widehat{\Pi}_j^{\frac{1-\sigma}{\sigma(1-\alpha)+\alpha}} \widehat{Y}^{\frac{1}{\sigma(1-\alpha)+\alpha}}$. This expression is intuitive. First, if P_j increases, capital accumulation becomes more expensive and investment decreases, because P_j captures the price of investment as well as consumption. Second, increases in sellers' incidence Π_j reduce capital accumulation because Π_j affects p_j inversely, so the value marginal product of capital falls with Π_j, decreasing the incentive to invest. Third, as the world gets richer, measured by an increase of world GDP ($\widehat{Y}$), capital accumulation in j increases to efficiently serve the larger world market.

In a recent influential paper, ACR demonstrate that the welfare effects of trade liberalization in a wide range of trade models can be summarized by the following sufficient statistics: $\widehat{W}_j = \widehat{\lambda}_{jj}^{\frac{1}{1-\sigma}}$, where λ_{jj} denotes the share of domestic expenditure and "hat" denotes the ratio of the counterfactual and baseline value. Motivated by ACR, we show (in online Appendix E) that the change in capital can directly affect welfare by deriving an extended ACR formula:

$$\widehat{W}_j = \widehat{K}_j^{\alpha} \widehat{\lambda}_{jj}^{\frac{1}{1-\sigma}}. \tag{26}$$

Equation (26) implies that an increase of steady-state capital will, ceteris paribus, increase welfare. The extended ACR formula given in (26) holds in and out-of steady state. Furthermore, as demonstrated in online Appendix E, we can express $\widehat{K}_j$ in terms of $\widehat{\lambda}_{jj}$ in steady state, leading to $\widehat{W}_j = \widehat{\lambda}_{jj}^{\frac{1}{(1-\alpha)(1-\sigma)}}$. This expression nicely highlights the similarity of introducing capital or intermediates in the steady state (compare with ACR, p. 115). In steady-state, the new level of capital stocks can be equally thought of as different amounts of intermediate goods in production. However, intermediate goods are not able to explain dynamic adjustments to trade liberalization, as highlighted by Baier et al. (2014) and Anderson and Yotov (2016), and which is at the heart of our structural, dynamic model.

initial static trade diversion effects. Details are available in Table A4 of online Appendix J.

We are also able to derive an ACR-like welfare formula, which only depends on $\widehat{\lambda}_{jj,t}$ and parameters when taking into account the transition (see online Appendix E.2). However, we will typically not observe changes in $\lambda_{jj,t}$ over time solely driven by the counterfactual under consideration. While the standard approach in a static setting is to measure welfare in terms of real GDP, our dynamic capital-accumulation framework requires some adjustments to this standard approach for the following reasons: (i) Transition between steady states is not immediate due to the gradual adjustment of capital stocks. Given our upper level equilibrium, we are able to solve the transition path for capital accumulation simultaneously in each of the N-countries in our sample.[28] (ii) Consumers in our setting divide their income between consumption and investment. Thus, only part of GDP is used to derive utility. In order to account for these features of our model, we follow Lucas (1987) and calculate the constant fraction ζ of aggregate consumption in each year that consumers would need to be paid in the baseline case to give them the same utility they obtain from the consumption stream in the counterfactual ($C^c_{j,t}$). Specifically, we calculate:

$$\sum_{t=0}^{\infty} \beta^t \ln\left(C^c_{j,t}\right) = \sum_{t=0}^{\infty} \beta^t \ln\left[\left(1+\frac{\zeta}{100}\right) C^b_{j,t}\right] \Rightarrow$$

$$\zeta = \left(\exp\left[(1-\beta)\left(\sum_{t=0}^{\infty} \beta^t \ln\left(C^c_{j,t}\right) - \sum_{t=0}^{\infty} \beta^t \ln\left(C^b_{j,t}\right)\right)\right] - 1\right) \times 100. \qquad (27)$$

4 Empirical Analysis

There are two possible approaches to take system (20)-(25) to data. The first is a *calibration* approach. It uses the model to recover some parameters and variables, e.g. bilateral trade costs, to match some data moments perfectly, and borrows other parameters, e.g. the trade elasticity, from the literature in order to perform counterfactual simulations. The second is an *estimation* approach. It employs the structural model equations to estimate own structural

[28] Given our closed-form solution of the policy function for capital and an initial capital stock $K_{j,0}$, this boils down to solving system (20)-(25) for all countries at each point of time. Alternatively, we used Dynare (http://www.dynare.org/) and the implied first-order conditions of our dynamic system to solve the transition path. Both lead to identical results. For further computational details see online Appendix B.

parameters, which are then used in the counterfactual experiments.

Each approach has advantages and disadvantages, cf. Dawkins et al. (2001). While our framework readily lends itself to the *calibration* approach, our model is straightforward to implement econometrically and, therefore, it offers a unique opportunity to capitalize on the advantages of the *estimation* approach while making some meaningful contributions to the existing literature. Specifically, it simultaneously enables us to test and establish the causal relationships between trade, income, and growth, and it also delivers all the key parameters needed to perform counterfactuals.

The parameter estimates that we obtain are comparable to standard values from the existing literature to establish the credibility of our methods. The econometric framework includes as a special case the reduced-form income-and-trade specification from Frankel and Romer (1999), but also expands on it by proposing novel instruments for trade openness and by introducing an additional estimating equation for capital accumulation while highlighting important contributions of our structural approach. Section 4.1 presents the estimation strategy and some econometric challenges. Section 4.2 describes the data and Section 4.3 presents the estimates.

4.1 Econometric Specification

We translate our theoretical model into estimating equations in two steps. We begin with the estimation strategy for the lower level, the gravity model of trade flows. Then, we describe the estimation strategy for the upper level equations for income and for capital.

4.1.1 Lower Level Econometric Specification: Trade

To obtain sound econometric estimates of bilateral trade costs and, subsequently, of the multilateral resistances that enter the income and capital equations, several econometric challenges must be met. First, we follow Santos Silva and Tenreyro (2006) in the use of the Poisson Pseudo-Maximum-Likelihood (PPML) estimator to account for the presence of heteroskedasticity and zeros in trade data. Second, we use time-varying, directional (exporter and importer), country-specific fixed effects to account for the unobservable multilateral resistances. Importantly, in addition to controlling for the multilateral resistances, the fixed effects in our econometric specification also absorb national output and expenditure and, therefore, control for all dynamic forces from our theory. Third, to avoid the critique from Cheng and Wall (2005) that "[f]ixed-effects estimation is sometimes criticized when applied to data pooled over consecutive years on the grounds that dependent and independent variables cannot fully adjust in a single year's time." (footnote 8, p. 52), we use 3-year intervals.[29]

The final step, which completes the econometric specification of our trade system, is to provide structure behind the unobservable bilateral trade costs $t_{ij,t}$. We employ a flexible country-pair fixed effects approach in order to account for all (observable and unobservable) time-invariant trade costs. In addition, we use RTAs to capture the effects of trade policy.[30] Econometrically, we have to address the potential endogeneity of RTAs. The issue of RTA endogeneity is well-known in the trade literature[31] and to address it, we adopt the method from Baier and Bergstrand (2007) and use country-pair fixed effects in order to account for the unobservable linkages between the RTAs and the error term in our trade regressions.

Taking all of the above considerations into account, we employ PPML to estimate the following econometric specification of the *Trade equation* (20) from our structural system:

[29] Trefler (2004) also criticizes trade estimations pooled over consecutive years. He uses three-year intervals. Baier and Bergstrand (2007) use 5-year intervals. Olivero and Yotov (2012) provide empirical evidence that gravity estimates obtained with 3-year and 5-year lags are very similar, but the yearly estimates produce suspicious trade cost parameters. Here, we use 3-year intervals in order to improve efficiency, but we also experiment with 4- and 5-year lags to obtain qualitatively identical and quantitatively very similar results.

[30] We chose to focus exclusively on RTAs in order emphasize the methodological contributions of our work. In principle, we also may introduce tariffs and other time-varying trade costs in the estimating gravity equation (28). However, bringing tariff revenues fully into the model opens Pandora's Box, because much of their distortionary effect (and much of the difficulty of negotiating regional trade agreements) is due to dispersion of rates across sectors within countries. Moreover, a proper treatment of effects of trade agreements via government revenue should in principle include effects on *domestic* distortionary tax collections, effects likely to be much larger (because tax rates are higher) than those from trade tax revenues. We refer the interested reader to Anderson and van Wincoop (2001) and to Egger et al. (2011) for modeling and empirical investigation of the role of heterogeneous tariff revenues in gravity models. Instead, here we choose to abstract from modeling such time-varying trade costs and potential tariff revenues and rents in order to be able to clearly isolate the pure dynamic effects of a single one-time trade shock, such as the introduction or the removal of an RTA, which will enable us to focus on and emphasize our methodological contributions.

[31] See for example Trefler (1993), Magee (2003) and Baier and Bergstrand (2002, 2004).

$$X_{ij,t} = \exp[\eta_1 RTA_{ij,t} + \chi_{i,t} + \pi_{j,t} + \mu_{ij}] + \epsilon_{ij,t}, \tag{28}$$

where $RTA_{ij,t}$ is a dummy variable equal to 1 when i and j have a RTA in place at time t, and zero elsewhere. $\chi_{i,t}$ denotes the time-varying source-country dummies, which control for the outward multilateral resistances and countries' output shares. $\pi_{j,t}$ encompasses the time varying destination country dummy variables that account for the inward multilateral resistances and total expenditure. μ_{ij} denotes the set of country-pair fixed effects that should absorb the linkages between $RTA_{ij,t}$ and the remainder error term $\epsilon_{ij,t}$ in order to control for potential endogeneity of the former. The error term is introduced because the relation between $X_{ij,t}$ and $\exp[\eta_1 RTA_{ij,t} + \chi_{i,t} + \pi_{j,t} + \mu_{ij}]$ holds on average but not for each observation (see Goldberger, 1991; Santos Silva and Tenreyro, 2006).[32] Importantly, μ_{ij} will absorb all time-invariant gravity covariates, such as bilateral distance, contiguous borders, common language and colonial ties, along with any other time-invariant determinants of trade costs that are not observable. We use the estimates of the country-pair fixed effects $\widehat{\mu}_{ij}$ from equation (28) to measure directly international trade costs in the absence of RTAs (for details please see online Appendix F):

$$\left(\widehat{t}_{ij}^{NORTA}\right)^{1-\sigma} = \exp\left[\hat{\mu}_{ij}\right]. \tag{29}$$

Bilateral trade costs that account for the presence of RTAs are constructed as follows:

$$\left(\widehat{t}_{ij,t}^{RTA}\right)^{1-\sigma} = \exp\left[\widehat{\eta}_1 RTA_{ij,t}\right]\left(\widehat{t}_{ij}^{NORTA}\right)^{1-\sigma}. \tag{30}$$

Below, we use (30) to study the dynamic general equilibrium effects of NAFTA and globalization in general on growth and welfare.

[32] The rich fixed effects structure (including bilateral fixed effects, exporter-time fixed effects, and importer-time fixed effects) of specification (28) supports the assumption of a stochastic error term, $\epsilon_{ij,t}$. However, it may still be possible that $\epsilon_{ij,t}$ carries some systematic trade cost information. Anderson et al. (2015) propose a hybrid approach, dubbed *"estibration"*, which uses an empirical gravity model similar to (28) to obtain estimates of the effects of trade policy and then adds the error to the trade cost function in order to match the trade flows data perfectly. We experimented with this method here to obtain virtually identical results, both in the estimations of our *Income* and *Capital* equations as well as in the counterfactual experiments. This gives us confidence to proceed and perform our main analysis while treating $\epsilon_{ij,t}$ as a stochastic error term.

4.1.2 Upper Level Econometric Specification: Income and Capital

Estimation of the equation for income allows a test for a causal relationship between trade openness and the value of production, and also obtains estimates of the trade elasticity and of the labor and capital shares in production. Estimation of the capital accumulation equation allows a test for a causal relationship between trade openness and growth and also delivers estimates of the capital depreciation rates. Begin with the estimating equation for income.

Income. Transforming the theoretical specification for income into an estimating equation is straightforward: substitute equation (23) for prices into equation (24), solve for $Y_{j,t}$ and express the resulting equation in natural logarithmic form:

$$\ln Y_{j,t} = \frac{1}{\sigma}\ln Y_t + \frac{\sigma-1}{\sigma}\ln\frac{A_{j,t}}{\gamma_j} + \frac{(\sigma-1)(1-\alpha)}{\sigma}\ln L_{j,t} + \frac{(\sigma-1)\alpha}{\sigma}K_{j,t} - \frac{1}{\sigma}\ln\left(\frac{1}{\Pi_{j,t}^{1-\sigma}}\right). \quad (31)$$

We keep the expression for the outward multilateral resistance as a power transform, $\Pi_{j,t}^{1-\sigma}$, because we can recover this power term directly from the exporter-fixed effects from the lower level trade gravity estimation procedures without the need to assume any value for the elasticity of substitution σ.[33] As demonstrated below, our methods also enable us to obtain our own estimate of σ.

We address several important econometric challenges in order to obtain sound estimates of the key coefficients in equation (31). First, we do not observe $A_{j,t}$ and data on γ_j are not available. To account for the latter, we introduce country-specific fixed effects ϑ_j. These country fixed effects will also absorb any time-invariant differences and variation in technology $A_{j,t}$ at the country level. In order to control for additional time-varying effects that may have affected technology globally, we also introduce time fixed effects ν_t. The year fixed effects will also control for any other common time-varying variables that may affect output in addition to the time-varying covariates that enter our specification explicitly. In addition, the year dummies will absorb the structural world output term $\frac{1}{\sigma}\ln Y_t$.

While we believe that the country fixed effects and the year fixed effects in our specifica-

[33] In fact, we capitalize on the property of the PPML estimator to be perfectly consistent with structural gravity (see Fally, 2015; Anderson et al., 2015), in order to recover the power transforms of the multilateral resistances directly from the directional gravity fixed effects.

tion will absorb most of the variability in technology $A_{j,t}$, it is still possible that we would miss some high-frequency moves in $A_{j,t}$ at the country-year level. We account for such movements by introducing several additional covariates as proxies for productivity. These include a direct TFP measure, a measure of R&D, and a measure of the occurrence of natural disasters. We label the vector of these additional covariates $TFP_{j,t}$.[34] Taking the above considerations into account, equation (31) becomes:

$$\ln Y_{j,t} = \kappa_1 \ln L_{j,t} + \kappa_2 \ln K_{j,t} + \kappa_3 \ln \left(\frac{1}{\Pi_{j,t}^{1-\sigma}} \right) + TFP_{j,t}\kappa_4 + \nu_t + \vartheta_j + \varepsilon_{j,t}, \qquad (32)$$

where $\varepsilon_{j,t}$ is a remainder error term accounting for the fact that the relation between $\ln Y_{j,t}$ and the conditional expectation of $\ln Y_{j,t}$, given by $\kappa_1 \ln L_{j,t} + \kappa_2 \ln K_{j,t} + \kappa_3 \ln \left(\frac{1}{\Pi_{j,t}^{1-\sigma}} \right) + TFP_{j,t}\kappa_4 + \nu_t + \vartheta_j$, holds on average but not for each observation. Here, $\kappa_1 = (\sigma - 1)(1-\alpha)/\sigma$, $\kappa_2 = (\sigma - 1)\alpha/\sigma$, and $\kappa_3 = -1/\sigma$. Importantly, a significant estimate of the coefficient on the MR/trade openness term, $\widehat{\kappa}_3$, will support a causal relationship of trade on income. In addition, $\widehat{\kappa}_3$ can be used to recover the elasticity of substitution directly as $\widehat{\sigma} = -1/\widehat{\kappa}_3$.[35] With $\widehat{\sigma}$ at hand, we can also obtain the capital share of production as $\widehat{\alpha} = \widehat{\kappa}_2\widehat{\sigma}/(\widehat{\sigma} - 1) = \widehat{\kappa}_2/(1 + \widehat{\kappa}_3)$. Finally, our model implies the following structural relationship between the coefficients on the three covariates in (32), $\kappa_1 + \kappa_2 = 1 + \kappa_3$.

The next challenge to estimating equation (32) is that our measure of trade openness, $\ln \left(\frac{1}{\Pi_{j,t}^{1-\sigma}} \right)$, is endogenous by construction, because it includes own national income. The issue is similar to the endogeneity concern in the famous Frankel and Romer (1999). Our work complements and builds on Frankel and Romer (1999) in two ways. First, in combination, equations (28) and (32) deliver a structural foundation for the reduced-form trade-and-

[34]Further details on these variables and the data used for their construction appear in Section 4.2. We are aware of the successful efforts to estimate productivity with available firm-level data, cf. Olley and Pakes (1996) and Levinsohn and Petrin (2003). However, the aggregate nature of our study does not allow us to implement those estimation approaches. The plausible estimates of the production function parameters that we obtain in the empirical analysis are encouraging evidence that our treatment of technology with controls and country as well as time fixed effects is effective.

[35]The ability to estimate σ and correspondingly the trade elasticity $(1 - \sigma)$ is a nice feature of our model, especially because this parameter is viewed in the literature as the single most important parameter in international trade (see ACR and Costinot and Rodríguez-Clare, 2014). Furthermore, we will be able to compare our estimates with existing estimates in order to gauge the success of our methods.

income specification from Frankel and Romer (1999). Frankel and Romer use a version of *Trade equation* (28) to instrument for international trade, which enters their *Income equation* corresponding to equation (32) directly, to replace our structural term $\ln\left(1/\Pi_{j,t}^{1-\sigma}\right)$. Instead, in our specification, the effects of trade and trade openness on income are channeled via the structural trade term $\ln\left(1/\Pi_{j,t}^{1-\sigma}\right)$. Importantly, this will enable us not only to test for a causal relationship between trade openness and income, but also to recover an estimate for the elasticity of substitution $\hat{\sigma} = -1/\hat{\kappa}_3$.[36]

Our second contribution in relation to Frankel and Romer (1999) and related studies (see footnote 10) that have estimated trade-and-income regressions is that we propose three new instruments for trade openness. The first instrument eliminates the endogeneity resulting from own GDP by calculating the multilateral resistances based on international trade linkages only, removing the intra-national components that include national income and therefore cause endogeneity:[37]

$$\tilde{\Pi}_{i,t}^{1-\sigma} = \sum_{j\neq i}\left(\frac{t_{ij,t}}{P_{j,t}}\right)^{1-\sigma}\frac{Y_{j,t}}{Y_t}. \tag{33}$$

Despite removing the endogeneity of own GDP, $\tilde{\Pi}_{i,t}^{1-\sigma}$ may still not be completely exogenous. The reason is that higher-order endogeneity may be present based on equation (33) due to the indirect relationship between own national income and (i) the national incomes of all other countries and (ii) the inward multilateral resistances of all other countries. Such effects are indirect and tend to be small. Nevertheless, in theory such effects are present and may affect our estimates. To test for sensitivity to such residual endogeneity, we also employ a version of the original instrument proposed by Frankel and Romer (1999) in addition to the new instrument that we propose here. More specifically, we employ the inverse of the Frankel-Romer instrument since our structural trade openness index technically measures

[36] In the empirical analysis below we estimate system (28)-(32) with the original Frankel-Romer methods and with our structural approach and we compare our results.

[37] This procedure is akin to the methods from Anderson et al. (2014), who use $\tilde{\Pi}_{i,t}^{1-\sigma}$ to calculate Constructed Foreign Bias, defined as the ratio of predicted to hypothetical frictionless foreign trade, aggregating over foreign partners only, $CFB_i = \tilde{\Pi}_{i,t}^{1-\sigma}/\Pi_{i,t}^{1-\sigma}$, where $\Pi_{i,t}^{1-\sigma}$ is the standard, all-inclusive outward MR.

the inverse of trade openness.

The second instrument that we introduce capitalizes on the structural relationships in our model and on the original intuition from Frankel and Romer (1999) to use labor instead of GDP to proxy for country size.[38] Specifically, we construct our second structural instrument by solving the multilateral resistance system with labor (instead of output) shares used as weights. Finally, our third instrument capitalizes on the panel dimension of our data and, once again, solves the multilateral resistance system, but this time with the initial levels of output used instead of the current output values. We offer further details on the instruments and their performance in Section 4.3.

The final challenge with the estimation of Specification (32) is that the labor and capital covariates are potentially endogenous as well. In Section 4.3 we account for these endogeneity concerns sequentially and we also treat all regressors from specification (32) simultaneously as endogenous by using a series of instruments that pass all relevant econometric IV tests.

Capital. Our theory allows us to go a step further in the econometric modeling of the relationship between trade and growth. Specifically, in addition to offering a structural foundation for the empirical trade-and-income system from Frankel and Romer (1999), we complement it with an additional estimating equation that captures the effects of trade (liberalization) on capital accumulation, our driver for growth. Equation (25) translates into a simple log-linear econometric model:

$$\ln K_{j,t} = \psi_1 \ln E_{j,t-1} + \psi_2 \ln K_{j,t-1} + \psi_3 \ln P_{j,t-1} + \varsigma_{j,t}. \tag{34}$$

Here, $\psi_1 = \delta$ captures the positive relationship between investment and the value of marginal product of capital. As discussed in our theory section, this relationship is driven by the general-equilibrium impact of changes in trade costs on factory-gate prices. $\psi_2 = 1-\delta$ captures the dependence of current on past capital stock. Finally, $\psi_3 = -\delta$ captures the intuitive inverse relationship between capital accumulation and the prices of consumption

[38] We thank an anonymous referee for suggesting this instrument.

and investment goods, which also capture the indirect, general-equilibrium effects of changes in trade costs on capital accumulation. Thus, a significant estimate of ψ_3 will support a causal relationship of trade on capital accumulation. Finally, our model implies the following structural relationships $\psi_1 = -\psi_3$ and $\psi_1 = 1 - \psi_2$.[39]

Several econometric challenges must be met to estimate equation (34). First, each of the three regressors in specification (34) is potentially endogenous. We will address this challenge with an instrumental variable estimator. Second, equation (34) describes a dynamic process where capital stock in the current period is a function of capital stock in past periods, i.e., the dependent variable is determined by its past realizations. As discussed in detail in Roodman (2009), this gives rise to *dynamic panel bias* since the dependent variable is clearly correlated with country-specific effects in the error term. A straightforward approach to mitigate the dynamic panel bias is to explicitly control for the country fixed effects in our panel with the Least Squares Dummy Variables (LSDV) estimator. Specifically, we add to equation (34) country fixed effects (ϑ_j) and year fixed effects (ν_t) in order to control for any unobserved and omitted time-varying global effects that may affect capital accumulation:

$$\ln K_{j,t} = \psi_1 \ln E_{j,t-1} + \psi_2 \ln K_{j,t-1} + \psi_3 \ln P_{j,t-1} + \nu_t + \vartheta_j + \varsigma_{j,t}, \tag{35}$$

where $\varsigma_{j,t}$ is the remainder error term accounting for the fact that $\ln K_{j,t}$ and the conditional expectation of $\ln K_{j,t}$ given by $\psi_1 \ln E_{j,t-1} + \psi_2 \ln K_{j,t-1} + \psi_3 \ln P_{j,t-1} + \vartheta_j + \nu_t$ holds on average but not for each observation. Additionally, ν_t and ϑ_j control for the parameters $\delta \ln\left[(\alpha\beta\delta)/(1-\beta+\beta\delta)\right]$. In combination with the year dummies, the country fixed effects will not only mitigate the dynamic bias but also will control for any time-invariant country-specific characteristics that may affect capital accumulation but are omitted from our model, thus alleviating endogeneity concerns.

The rich set of fixed effects may not fully absorb all possible causes for endogeneity. Furthermore, the country fixed effects do not completely absorb the correlation between the

[39] In addition to delivering a single depreciation parameter δ, equation (34) can be used to estimate country-specific depreciation parameters by interacting each of the terms of the right-hand side with country dummies. We experiment with such specifications in our empirical analysis.

dependent variable and the dynamic error term and our estimates are still subject to the Nickell (1981) dynamic bias. In order to address these concerns we use a series of instrumental variables and we employ the Arellano and Bond (1991) linear generalized method of moments (GMM) estimator. Further details on our empirical strategy are presented in Section 4.3.

4.1.3 A Structural Estimating System of Trade, Income, and Growth

In combination, equations (28), (32), and (35), deliver the econometric version of our structural system of growth and trade:

$$Trade: \quad X_{ij,t} = \exp[\gamma_1 RTA_{ij,t} + \chi_{i,t} + \pi_{j,t} + \mu_{ij}] + \epsilon_{ij,t}, \tag{36}$$

$$Income: \quad \ln Y_{j,t} = \kappa_1 \ln L_{j,t} + \kappa_2 \ln K_{j,t} + \kappa_3 \ln\left(\frac{1}{\Pi_{j,t}^{1-\sigma}}\right) + TFP_{j,t}\kappa_4 + \nu_t + \vartheta_j + \varepsilon_{j,t}, \tag{37}$$

$$Capital: \quad \ln K_{j,t} = \psi_1 \ln E_{j,t-1} + \psi_2 \ln K_{j,t-1} + \psi_3 \ln P_{j,t-1} + \nu_t + \vartheta_j + \varsigma_{j,t}. \tag{38}$$

With system (36)-(38) we obtain estimates of the key parameters needed to calibrate our model of trade and growth. In addition, the system will enable us to isolate and identify the causal effect of trade on income and growth via the estimates of κ_3 and ψ_3 on the trade terms $\ln\left(\frac{1}{\tilde{\Pi}_{j,t}^{1-\sigma}}\right)$ and $\ln P_{j,t-1}$ in our *Income equation* (32) and *Capital equation* (34), respectively. We demonstrate below. Before that we describe our data.

4.2 Data

Our sample covers 82 countries over the period 1990-2011.[40] These countries account for more than 98 percent of world GDP during that period. The data include trade flows, GDP, employment, capital and RTAs. Bilateral trade cost proxies are data on standard gravity variables including distance, common language, contiguity and colonial ties along with regional trade agreements in effect.

Data on GDP, employment, capital stocks, and total factor productivity (TFP) are from the Penn World Tables 8.0.[41] The Penn World Tables 8.0 offer several GDP variables.

[40]The list of countries and their respective labels can be found in online Appendix G.

[41]These series are now maintained by the Groningen Growth and Development Centre and reside at http://www.rug.nl/research/ggdc/data/pwt/.

Following the recommendation of the data developers, we employ *Output-side real GDP at current PPPs* ($CGDP^o$), which compares relative productive capacity across countries at a single point in time, as the initial level in our counterfactual experiments, and we use *Real GDP using national-accounts growth rates* ($CGDP^{na}$) for our output-based cross-country income regressions. The Penn World Tables 8.0 include data that enables us to measure employment in effective units. To do this we multiply the *Number of persons engaged in the labor force* with the *Human capital index*, which is based on average years of schooling. Capital stocks (at constant 2005 national prices in mil. 2005USD) in the Penn World Tables 8.0 are constructed based on cumulating and depreciating past investment using the perpetual inventory method. As a main measure for total factor productivity we use TFP level at current PPPs. For more detailed information on the construction and the original sources for the Penn World Tables 8.0 series see Feenstra et al. (2013). In addition, we also employ a measure for research and development (R&D) spending, which is taken from the World Development Indicators. Finally, we experiment with an instrument for occurrence of natural disasters, which comes from EM-DAT - The International Disaster Database.[42]

Aggregate trade data come from the United Nations Statistical Division (UNSD) Commodity Trade Statistics Database (COMTRADE). The trade data in our sample includes only 5.8 percent of zeroes due to its aggregate nature. The RTA-dummy is constructed based on information from the World Trade Organization. A detailed description of the RTA data used and the data set itself can be found at http://www.ewf.uni-bayreuth.de/en/research/RTA-data/index.html. Finally, data on the standard gravity variables, i.e., distance, common language, colonial ties, etc., are from the CEPII's Distances Database.

[42] http://www.emdat.be/database.

4.3 Estimation Results and Analysis

4.3.1 Trade Costs

Specification (28) delivers an estimate of the average treatment effect of RTAs that is equal to 0.827 (std.err. 0.135), which is readily comparable to the corresponding index of 0.76 from Baier and Bergstrand (2007).[43] This gives us confidence to use our estimate of the RTA effects to proxy for the effects of trade liberalization in the counterfactual experiments.

Without going into details and merely for demonstration purposes of the magnitudes of trade costs implied using country-pair fixed effects to calculate them, we briefly discuss several properties of the bilateral trade costs, which are constructed as $\widehat{t}_{ij} = exp(\hat{\mu}_{ij})^{1/(1-\hat{\sigma})}$, where we use a conventional value of the elasticity of substitution, $\hat{\sigma} = 6$.[44] All estimates of $\widehat{t}_{ij}$ are positive and greater than one. The mean estimate of bilateral trade costs is 5.569 (std.dev. 4.216). Estimates of the bilateral fixed effects vary widely but intuitively across the country pairs in our sample. For example, we obtain the lowest estimates of $\widehat{t}_{ij}$ for countries that are geographically and culturally close and economically integrated. The smallest estimate of bilateral trade costs is for the pair Malaysia-Singapore (1.184), followed by Belgium-Netherlands (1.327). While more than 95% of our estimates of bilateral trade costs are smaller than 12, we also obtain some very large estimates of $\widehat{t}_{ij}$ for countries that are isolated economically and geographically. The largest estimate is for the pair Uzbekistan-Dominican Republic (132.7). Most other pairs with very large bilateral trade cost estimates also include as one partner one of the less developed former Soviet republics. This result is consistent with the findings of Waugh (2010) that trade flows in less developed countries are subject to larger trade costs. Another outlier pair is Israel-Iran (30.21). We note that these estimates are obtained directly from the pair fixed effects as a very flexible proxy for trade

[43] Our RTA estimate suggest a partial equilibrium increase of 129% ($100 \times [\exp(0.827) - 1]$) in bilateral trade flows among member countries.

[44] Head and Mayer (2014) survey the related literature and report average values and standard deviations of 744 elasticity estimates obtained from a sample of 32 papers. The mean estimate of σ from Head and Mayer (2014) when the selection criteria is "structural gravity" estimation, as in our analysis, is $\hat{\sigma} = 6.13$. Importantly, below we obtain our own structural estimate of $\hat{\sigma} = 5.847$ (std.err. 0.620), which is remarkably close to (and, in fact, not statistically different from) Head and Mayer's index. Here, just for presenting the magnitude of the trade costs, we assume the value of 6. See for details online Appendix F.

costs. This suggests that the standard set of proxies for trade costs that are routinely used in gravity estimations may miss to account for some important obstacles to international trade, especially among less developed pairs.

4.3.2 Income

Estimates from various specifications of *Income equation* (32) are reported in Table 1. All specifications include year fixed effects and country fixed effects, and we report standard errors that are robust or bootstrapped when a generated regressor enters the estimating equation directly. We begin with two benchmark specifications. In columns (1) and (2) of Table 1, respectively, we offer results from an unconstrained and from a constrained estimation of a standard Cobb-Douglas production function. As can be seen from the table, both the labor and the capital shares in each specification are within the theoretical bounds $[0;1]$ even though the capital share is a bit higher than the standard corresponding value from the literature.[45]

Column (3) of Table 1 reports estimates of a Frankel-Romer type specification, where we introduce the log of international trade/total exports, $\ln\sum_{j\neq i} X_{ij,t}$, as an additional regressor in the unconstrained Cobb-Douglas estimation from column (1). As correctly noted by Frankel and Romer (1999), the trade regressor is endogenous. Therefore, we follow Frankel and Romer's strategy and perform an IV estimation, where bilateral exports are predicted in a first-stage gravity model by the standard gravity regressors (see for details online Appendix F) and by the logarithms of exporter and importer populations. Our first-stage gravity regression follows the recommendation of Feyrer (2009b) not to use exporter and importer fixed effects in a Frankel-Romer setting because the directional fixed effects will contaminate the IV estimation since they implicitly account for income and expenditure.

Results from the IV experiment are presented in column (3) of Table 1. Consistent with the findings of Frankel and Romer (1999), our estimates confirm that the effect of trade on income/growth is positive and statistically significant. In addition, our instruments pass the

[45]Below, we offer some validity checks with respect to the estimated capital share. Moreover, in the sensitivity analysis for our counterfactuals we experiment with alternative values for α.

underidentification and the “weak identification” test that we also report in the bottom of panel A. Overall, the results from the Frankel-Romer experiment are consistent with those from the literature.

In columns (4) and (5) of Table 1, we replace the trade variable from the reduced-form Frankel-Romer specification with our structural trade openness measure. The estimates in column (4) are unconstrained, while the specification in column (5) imposes the structural restrictions of our theory. The constrained and the unconstrained results are very similar, and not statistically different from each other. This is encouraging preliminary evidence in support of our model. It also enables us to focus interpretation on the constrained estimates from column (5), where we see that estimates have expected signs and are statistically significant at any conventional level. Importantly, we find that trade openness leads to higher income. This is captured by the negative and significant estimate of the coefficient of our inverse theoretical measure of trade openness $\ln\left(1/\widehat{\Pi_{j,t}^{1-\sigma}}\right)$. Thus, our model and estimates offer evidence for a causal relationship between trade and income.

The structural properties of the model yield estimates of the elasticity of substitution, $\hat{\sigma}$, and of the capital share, $\hat{\alpha}$, which are reported at the bottom of column (5). The inferred value of $\widehat{\sigma} = -1/\widehat{\kappa}_3 = 4.084$ falls comfortably within the distribution of the existing (Armington) elasticity numbers from the trade literature, which usually vary between 2 and 12. (See footnote 17). The inferred estimate of the capital share $\widehat{\alpha} = 0.572$ is a bit higher than expected but falls within the theoretically required interval [0;1].

The specification in column (6) addresses potential high-frequency (country-year) technology changes not controlled for with the set of country and year fixed effects in the econometric model. We introduce a direct TFP measure as a covariate, taken from the Penn World Tables. We obtain a positive and significant estimate on the coefficient of $TFP_{j,t}$. The addition of the TFP measure does not affect our findings qualitatively, as all estimates are still statistically significant at any level and with signs as expected. However, the magnitudes of the effects of labor, capital, and trade openness are changed. Specifically, controlling for

TFP decreases the effects of effective labor and trade openness and leads to a higher estimate of the effect of capital. The reduction in importance of trade openness is attributable to the fact that multilateral resistance is part of TFP. The structural estimate of the elasticity of substitution increases to $\widehat{\sigma} = -1/\widehat{\kappa}_3 = 10.114$, which is now on the higher end of the distribution of corresponding estimates from the literature. In online Appendix C.1 we also add R&D and the occurrence of natural disasters as possible candidates that may affect productivity and income. None of the effects of these variables is significant and they do not affect the estimates of the effects of the other covariates in our specification. We capitalize on this result below, where we use the occurrence of natural disasters as an instrument in the IV specifications of our *Income equation*.

We account for endogeneity of trade openness in columns (7) and (8) of Table 1. First, in column (7), we use the new structural instrument that we proposed in Section 4.1.2, which is constructed after explicitly removing the endogenous components from the OMR/trade openness index. In addition, we also employ the lag of our openness regressor in order to mitigate simultaneity concerns. The IV results in column (7) are encouraging. All variables retain their signs and statistical significance. In addition, as evident from the test statistics reported at the bottom of panel A, our instruments pass the underidentification, the weak identification, and also the overidentification tests. Inspection of the first stage IV estimates reveals that both of our instruments are highly statistically significant and contribute significantly to explain the variability in the endogenous trade openness regressor. The estimates from panel B reveal that the structural parameters that we recover are also within the theoretical limits and are comparable to the estimates from column (6). In sum, our results suggest that the new instrument proposed here performs well. Nevertheless, in column (8) of Table 1, we also add the inverse of the Frankel-Romer instrument that we used to obtain the results from column (3). As noted earlier, we use the inverse of this instrument because our structural trade term is an inverse measure of trade openness by construction. The estimates in column (8) are virtually identical to those from column (7). In addition, once again, the instruments pass all IV tests. At the end of this section, we also discuss the performance of the other two instruments that we propose.

Next, we control for endogenous capital, endogenous labor, and endogenous TFP in columns (9), (10), and (11), respectively, of Table 1. Our approach is to endogenize one additional variable at a time while still treating all variables that already have been endogenized in previous specifications as endogenous. As a result, the estimates in column (11) are obtained with all covariates from equation (32) being treated as endogenous. In column (9), we use lagged capital stocks and occurrence of natural disasters to instrument for current capital stock. Then, in column (10), we also allow for endogenous labor in addition to endogenous capital and endogenous trade openness, and we add the log of population to instrument for labor in addition to the instruments for capital and those for openness. Finally, in column (11), we add lagged and 2-period lagged TFP as instruments for current TFP. The estimates from column (11), where trade openness, capital, labor, and TFP are all treated as endogenous, are very similar to those from column (8), where only trade openness was treated as endogenous. The values of the structural parameters from column (11) are also similar to the corresponding estimates from column (8). Finally, we note that the instruments that we use in each of specifications (9)-(11) pass all IV tests.

The last column of Table 1 presents our main results, obtained after controlling for endogeneity of all covariates (as in column (11)), while simultaneously imposing the structural constraints of our model (as in column (5)). Estimates of all covariates have expected signs, reasonable magnitudes, and are significant at any conventional level. The structurally estimated capital share is a bit higher than expected, but it is still within the theoretical bounds. With a value of 5.847, our estimate of elasticity of substitution is right in the middle of the standard range from the literature and it is not statistically different from the summary measure of $\sigma = 6.13$ reported in Head and Mayer (2014).[46]

[46] Our estimates reveal that the elasticity of income with respect to the Frankel-Romer measure of openness, which we obtain in column (3), is higher as compared to the elasticity with respect to our structural measure of openness. We offer two possible explanations. First, gravity theory may explain part of the differences. Specifically, we note that our structural measure of trade openness represents only one component of the

Given the importance of proper account for endogeneity in the relationship between trade and income/growth (see Frankel and Romer, 1999), and the interest that this issue has generated and attracted over the years in the profession (see Footnote 10), we devote the end of this section to discuss the performance of the two additional instruments that we proposed earlier. Estimation results are presented in Table 2. For brevity, we only present and discuss findings from the three key specifications for each of the two new instruments, which correspond to columns (7), (8), and (12) from Table 1. In addition, to ease comparison, the first three columns of Table 2 reproduce the corresponding estimates with the first instrument from Table 1. Columns (4)-(6) of Table 2 report estimates with the openness instrument that uses labor shares. Columns (7)-(9) of Table 2 report estimates with the openness instrument that uses initial output shares. Two main findings from Table 2 stand out. First, estimation results across the specifications with the three structural instruments are not statistically different from each other across the corresponding specifications. Second, similar to the first instrument, the two additional instruments pass all IV specification tests. The main implication of the results from Table 2 is that using any of the three instruments that we propose here would not result in any significant changes in our findings. We chose to focus on the first instrument that explicitly removes the direct endogeneity links because this instrument performed best in the first stage analysis and because this is the only instrument that remained significant when all three instruments were included simultaneously in the first-stage regressions.[47]

Overall, the parameter estimates of α and σ that we obtain in this section are plausible.

theoretically predicted trade variable from Frankel and Romer. Second, we add as a control in the income regression a direct TFP measure. Comparison between the results from columns (4) and (5) reveal that, while all of our estimates remain significant and with expected signs, the introduction of TFP affects the magnitude of our results and they become smaller.

[47] The loss in significance for some of the instruments when all three of them are included in the analysis simultaneously is not surprising since the three measures are highly correlated. We also experimented with various combinations of two of the new instruments. The combinations of instruments performed well. They passed the IV tests and delivered results that were virtually identical to those from Tables 1 and 2. However, the instrument that explicitly removes the direct endogeneity links always outperformed each of the other two instruments in the first-stage regressions. This reinforced our decision to use this instrument in the main analysis.

Furthermore, we view the stable and robust performance of our results across all the specifications in Table 1, which range from a very basic unconstrained OLS model (column (4)) to a constrained IV specification that allows for all structural terms to be endogenous (column (12)), as encouraging evidence in support of our model.

4.3.3 Capital

To estimate the capital accumulation equation (34) we use the main estimate of the elasticity of substitution $\hat{\sigma} = 5.847$ from our income regressions to construct $\ln P_{j,t-1}$ from the power transform of the inward multilateral resistance.[48] Equation (34) will enable us to recover capital depreciation rates (δ's) subject to the following relationships: $\psi_1 = \delta$; $\psi_2 = 1 - \delta$; and $\psi_3 = -\delta$. In addition, the estimate of the coefficient ψ_3 on $\ln P_{j,t-1}$ will enable us to test our theory for a positive relationship between trade and capital accumulation.

Begin with a simple OLS regression based on (34). Results are presented in column (1) of Table 3. The estimates of all three covariates are statistically significant at any conventional level and with expected signs. The estimate on the lagged capital stock variable is very close to one and very precisely estimated, capturing strong persistence as expected. Importantly, the estimate of the coefficient on the trade openness term $\ln P_{j,t-1}$ is negative and statistically significant, suggesting a positive causal relationship between trade openness and capital accumulation. The intuition is that, in accordance with our theory, the estimate of ψ_3 captures the inverse relationship between investment and the costs of investment (both direct and opportunity costs). Finally, we obtain a positive and significant estimate of the coefficient on the expenditure term $\ln E_{j,t-1}$, which, as suggested by our model, captures the positive relationship between the value of marginal product of capital and investment.

The estimates in column (2) of Table 3 are obtained from the same specification as in column (1) under the structural constraints of our model. All estimates are statistically significant at any conventional level and have expected signs. The capital depreciation rate

[48] Results are robust to using alternative values for σ. For example, below we will use our structural specification with $\hat{\sigma} = 5.847$ to recover a capital depreciation rate $\hat{\delta} = 0.061$. This estimate varies between 0.054 and 0.063 for corresponding values of $\hat{\sigma}$ equal to 3 and 12.

is relatively low at 1.6 percent. Possible reasons for the downward bias in our estimate of the depreciation include (i) endogenous regressors and (ii) Nickell dynamic panel bias (Nickell, 1981) due to the use of the lagged dependent variable as a regressor in specification (34).

In columns (3), (4), and (5) of Table 3, respectively, we sequentially treat the lags of trade openness, expenditure, and the stock of capital as endogenous. Our approach is to endogenize one additional variable at a time while still treating all variables that have been endogenized in previous specifications as endogenous. In column (3), we use two instruments for trade openness. These instruments include the second lag of the endogenous variable $\ln P_{j,t-1}$ and the second lag of the openness variable but, as discussed in section 4.1.2, constructed without intra-national components. In column (4), we instrument for lagged expenditure with the second lags of this variable and of the variable for occurrence of natural disasters. Finally, in column (5) we also instrument for the lagged capital stock variable with its second lag. The results from columns (3)-(5) are similar and in accordance with our findings from the simple baseline OLS specification from column (1). In addition, our instruments pass the IV tests of underidentification, weak identification, and overidentification.

The estimates in column (6) of Table 3 are obtained with the Least Squares Dummy Variables (LSDV) estimator with country and year fixed effects added to specification (34), while all covariates are still treated as endogenous. As noted in Roodman (2009), this is a natural first step to mitigate (but not to eliminate) the dynamic panel bias by purging the country fixed effects out of the error term. The estimates in column (6) are qualitatively identical and quantitatively similar to those from the previous specifications. The main difference is the increase in the magnitude of the estimate on the lagged value of expenditure. In addition, we see that the estimates on lagged capital stock and on trade openness are a bit smaller, the latter still statistically significant but marginally so. Once again, we note that the instruments from the LSDV specification pass all IV tests. Finally, we find that two of the three structural constrains of our theory are satisfied in this specification.

Our main estimates of the *Capital equation* are presented in column (7) of Table 3. To obtain these results we treat all regressors as endogenous and we use the full set of fixed effects, as in column (6), but under the structural constraints of our model. The effects of all structural terms are highly significant and with expected signs. The estimate of the capital depreciation rate is 6.1 percent, suggesting that the depreciation rate $\hat{\delta} = 0.016$ from column (2) was indeed biased due to endogeneity and dynamic panel biases.

Next, we employ the dynamic panel-data estimator proposed by Arellano and Bond (1991) and refined by Arellano and Bover (1995) and Blundell and Bond (1998) in order to account for the remaining Nickell bias, which may still be present in our sample even after the inclusion of the country fixed effects because the lagged dependent variable may still be correlated with the unobserved panel effects within each country group. Since the expenditure and trade openness regressors are also functions of capital, we treat those covariates as potentially subject to dynamic bias concerns as well. Thus, our set of instruments includes all lags of all three endogenous regressors. In addition, we add as level instruments our structural trade openness instrument, the occurrence of natural disasters and the second lags of the logarithms of capital and expenditure. As in all previous specifications, the estimates in column (8) are obtained with robust standard errors and year and country fixed effects.

The results from column (8) of Table 3 reveal that, as in our main specification from column (7), the estimates of all regressors in the *Capital equation* are statistically significant and have signs as expected. In addition, even though we do not impose any structural constraints, we see that the magnitudes of the estimates are comparable to those from previous specifications. Importantly, the test statistics for first and second order zero autocorrelation in first-differenced errors, which are reported in the bottom of Table 3, suggest that the null hypothesis of no-autocorrelation is not rejected. Finally, we note that while our instruments clearly pass any weak identification test, they do not pass the Sargan overidentification test by a large margin. We offer two explanations for this result. First, it is natural to expect that the Sargan test, which cannot identify separately the contribution of the "good" instruments that we employed in previous specifications, will be weakened by the inclusion of lags and lagged differences of the endogenous regressors.[49] Second, while the estimates in column (8) are obtained with robust errors, the Sargan statistic is obtained without controlling for possible heteroskedasticity, which weakens the test further. Despite the fact that our results do not pass the overidentification test, we find the estimates from column (8) encouraging because (i) they are not subject to the dynamic Nickell bias, and (ii) they are readily comparable to the estimates from all previous specifications, which range from a very basic unconstrained OLS model (column (1)), through an unconstrained IV-LSDV specification with all endogenous regressors (column (6)), through a constrained IV-LSDV specification that allows for all structural terms to be endogenous (column (7)).

In combination with the estimates from our income regressions, our capital regression results demonstrate that the theoretical model and its structural econometric system perform well empirically. The results provide evidence for the substantial causal impact of trade on income and capital accumulation. We obtain plausible estimates for all but one of the parameters needed for counterfactual experiments. The lone parameter that we borrow from the literature is the consumer depreciation rate.[50] Minimum values, maximum values, and (when appropriate) standard errors for each of the parameters in our model are reported in Table 4. The good empirical results validate our parameter estimates for use in the trade liberalization counterfactual experiments that follow. In addition, in the robustness analysis (see online Appendix C), we experiment with alternative values for all structural parameters to obtain qualitatively identical results and intuitive quantitive variations.

5 Counterfactual Experiments

Two counterfactual experiments reveal the implications of the estimated model for the effect of trade liberalization shocks on growth. The trade liberalization 'shocks' that we consider

[49]We experimented by using longer lags as instruments and the Sargan statistic that we report in Table 3 decreased by orders of magnitude. However, no set of lags that we experimented with passed the Sargan test. Therefore, we decided to report the specification that includes all lags.

[50]We note that the consumer discount factor is only relevant for discounting the welfare effects in our setting. This can be seen in online Appendix H, where we solve our system in changes using the methods from Dekle et al. (2008).

are NAFTA and a 6.4% fall in international trade costs for all countries (globalization). We also perform a series of sensitivity experiments using a different functional form for capital accumulation (derived in online Appendix K), allowance for intermediate goods (derived in online Appendix L), using a different functional form for the intertemporal utility function (derived in online Appendix M), and alternative values for the parameters of our model and study the effect of growth shocks on trade, where the growth shock is a 20% change of the capital stock in the United States (discussed in Section C.4 of the online Appendix). Additionally, we perform a validation experiment that compares our calculated theory-consistent, steady-state capital stocks with the observed capital stocks for 1994, showing a correlation coefficient of 0.98 (see for details online Appendix C.2).

The fitted model "data" includes (i) the observed data on labor endowments ($L_{j,t}$) and GDPs ($Y_{j,t}$) for our sample of 82 countries; (ii) constructed trade costs $t_{ij,t}^{1-\sigma}$ from estimates of equation (30); (iii) theory-consistent steady-state capital stocks according to the capital accumulation equation (25); and (iv) baseline preference-adjusted technology A_j/γ_j according to the market-clearing equation (23) and the production function equation (24). Hence, we back out theory-consistent steady-state capital stocks and preference-adjusted technology using our theory and GDP and employment data. We do that for a single point in time, ensuring that for the specific year GDP and employment data are matched perfectly in our baseline case. For the counterfactual analysis, we assume that preference-adjusted technology stays constant, while the capital stocks endogenously adjust according to our transition function. Online Appendix I offers a detailed description of our counterfactual setup and procedures. Parameter estimates in the baseline case include our estimates of the elasticity of substitution $\widehat{\sigma} = 5.847$ and the share of capital in the Cobb-Douglas production function $\widehat{\alpha} = 0.545$ from column (12) of Table 1, and the capital depreciation rate $\widehat{\delta} = 0.061$ from column (7) of Table 3. The consumers' discount factor is set equal to $\beta = 0.98$, a standard in the literature.[51]

[51] Alternatively, we could solve our system in changes following Dekle et al. (2007, 2008). The results are identical to the results from the system in levels using the system in changes derived in online Appendix H.

Trade imbalances are consistent with the data and the model. To obtain counterfactual effects uncontaminated by trade imbalances, we first calculate baseline values of all endogenous variables using the data and parameters described above with the fitted model constrained to multilateral trade balance: $\phi_{j,t} = 1$ for all j and t (in the spirit of Dekle et al., 2007; Ossa, 2014). These baseline values are then compared with the counterfactual values from the scenario of interest, where we also assume multilateral trade balance.

5.1 Dynamic Effects of NAFTA

Our first counterfactual experiment evaluates the welfare effects of NAFTA, extending the static effects literature to include the dynamic effects of NAFTA on member and non-member countries (see for recent examples Trefler, 2004; Romalis, 2007; Caliendo and Parro, 2015; Anderson and Yotov, 2016). Results reported in Table 5 are decomposed into three stages of increasing general equilibrium adjustment. The first column of Table 5 lists country names. The next three columns present the NAFTA effects on welfare, where reported numbers are percentage changes in welfare due to the implementation of NAFTA. Column (2) reports the "Conditional General Equilibrium" ("Cond. GE") effects of NAFTA, which include the direct effects of the bilateral changes in trade costs with resulting changes in the MRs (20)-(22) at constant GDPs. These indexes correspond to the Modular Trade Impact (MTI) effects from Head and Mayer (2014). Column (3) also allows for static GDP changes in response to formation of NAFTA. We label this scenario "Full Static GE" and it corresponds to the General Equilibrium Trade Impact (GETI) effects from Head and Mayer (2014). Finally, in columns (4) and (5), we turn on the capital accumulation channel to estimate the effects of NAFTA in "Full Dynamic GE" scenarios, one for the steady state and one for the transition.[52]

The main "takeaway" of our paper is that dynamic effects are big. Column (4) of Table 5 reports estimates from the "Full Dynamic GE, SS" scenario, which compares the initial steady

[52]Discussion of findings from related NAFTA studies and estimates of the effects of NAFTA on trade flows, the multilateral resistances, and the capital effects can be found in online Appendix J. Since the direct effects of NAFTA on bilateral trade are confined to members only, we devote the analysis in this section to the GE effects of NAFTA. According to our estimates NAFTA will increase members' trade by 129%.

state (SS) to the new steady state, where all capital is fully adjusted to take into account the introduction of NAFTA. Focusing on the NAFTA countries, steady state welfare is more than doubled by the dynamic capital accumulation forces in our framework. The additional dynamic gains are on average almost 1.5 percentage points. Turning to non-members of NAFTA, the dynamic effects are negative but small.

Properly discounted welfare effects on the transition path[53] are reported in column (5), labeled "Full Dynamic GE, trans." of Table 5. The dynamic gains to NAFTA members increase the static gains by over 60% (63% for Canada and Mexico, 62% for the U.S.). Hence, the additional dynamic gains for Canada, Mexico and the U.S. do not vary much. This is in contrast to the static gains from trade liberalization, which lead to bigger gains for the smaller economies. We label the magnifying effect of the dynamic channel the *dynamic path multiplier*, which takes a value of around 1.6 here. The discounted dynamic welfare effects on members are smaller than the welfare changes from column (4), but still big. As a share of initial welfare, the discounted dynamic effects increase the welfare for NAFTA members by about 2.06 percent. The negative effects of non-members increase by only 0.005 percentage points compared to the static effects.

In terms of income growth effects, we find a growth rate effect of NAFTA for the first 15 years of adjustment of about 0.116% per year. For the non-NAFTA countries we find a slight negative effect of -0.001% per year, resulting in an overall acceleration in growth rates of real GDP in NAFTA countries compared to non-NAFTA countries of about 0.117% per year. This is about a third of the corresponding finding of Estevadeordal and Taylor (2013), which is based on a treatment-and-control approach.

Our approach permits tracing the effects of trade liberalization on capital accumulation. Figure 1 depicts the transition path for capital stocks in four countries, the NAFTA members plus Singapore. Singapore is the outside country with the strongest negative impact of

[53] We follow Lucas (1987) and calculate the constant fraction ζ of aggregate consumption in each year that consumers would need to be paid in the baseline case to give them the same utility they obtain from the consumption stream in the counterfactual ($C^c_{j,t}$) as specified in equation (27) from Section 3.1.

NAFTA. Figure 1 reveals that the effects on NAFTA members are large and long-lived. The largest effect of about 13 percent increase in capital stock is for Canada, followed by about 8 percent for Mexico and 1.4 percent for U.S.[54] Most of the dynamic gains accrue initially, but there remain significant transitional dynamic gains more than 50 years after the formation of NAFTA. In contrast, our results suggest that the transitional effects on non-members are small. On average, we find that capital stock in the non-member countries would have been about 0.02 percent lower without NAFTA, ranging between -0.105 percent for Singapore to nearly zero for Uzbekistan, Iran and Turkmenistan.[55] According to Figure 1, there are no additional negative effects on Singapore after about 50 years after the implementation of NAFTA. We estimate that on average non-members reach a new steady state after about 10 years after the formation of NAFTA.

5.2 Dynamic Effects of Globalization

A second counterfactual experiment sheds more light on the effects of trade on growth in our model. Uniform globalization is assumed to increase $\widehat{t_{ij}^{1-\sigma}}$ for all $i \neq j$ by 38% (the estimate of the effects of globalization over a period of 12 years from Bergstrand et al., 2015).[56] The globalization effects in the four scenarios of columns (2)-(5) are presented in columns (6)-(9) of Table 5. All countries in the world benefit from globalization. Intuitively, through lowering trade costs globalization improves efficiency in the world, and since bilateral trade costs decrease for every country, the efficiency gains are shared among all countries too. Second, the benefits vary across countries with the biggest gains to relatively small countries

[54]The large increase in the capital stock for Canada is explained by the fact that many of the gains from trade between Canada and the U.S. have already been exploited due to the Canada-US FTA from 1989. This could be captured in our framework with a gravity specification that allows for pair-specific NAFTA effects. However, we use a common NAFTA estimate in order to emphasize our methodological contributions.

[55]The net negative effect on non-members is the result of three forces: i) Trade diversion due to NAFTA leads to increased trade resistance which translates into higher producer and consumer prices in the non-member countries; ii) At the same time, improved efficiency in NAFTA members would lead to trade creation between NAFTA and non-NAFTA members and lower the consumer prices in the latter; iii) Finally, larger income in NAFTA members will lead to more imports for those countries from all other countries in the world. The fact that we obtain negative net effects of capital accumulation in all our non-member countries reveals that the first, trade diversion, effect dominates the latter two, trade creation, effects. However, in principle, it is possible for the trade creation effect to dominate the negative impact of trade liberalization.

[56]With our estimated σ of 5.847, this corresponds to a decrease of t_{ij} by 6.43% for all $i \neq j$.

in close proximity to large markets. For example, Belgium, Ireland and Singapore are among the big winners in all scenarios. Third, comparison between the "Full Static GE" scenario and the "Cond. GE" scenario reveal that the additional general equilibrium forces in the "Full Static GE" case lead on average to doubling of the gains. Finally, we estimate strong dynamic effects of globalization. The "Full Static GE" gains increase by more than 60% in the dynamic scenario, implying a *dynamic path multiplier* of 1.6.

6 Conclusions

The simplicity of our dynamic structural estimating gravity model derives from severe abstraction: each country produces one good only and there is no international lending or borrowing. Difficult but important extensions of the model entail relaxing each restriction while preserving the closed-form solution for accumulation. This may be feasible because either relaxation implies a contemporaneous allocation of investment across sectors and/or countries with an equilibrium that can nest in the intertemporal allocation of the dynamic model. A multi-good model will bring in the important force of specialization. An international borrowing model will bring in another dynamic channel magnifying differential growth rates. Considering foreign direct investments will lead to additional spill-over effects from liberalizing countries to non-liberalizing countries. Allowing for international labor mobility will lead to reallocation of labor across countries and, thereby, change the relative sizes of countries. Allowing for success in the extension can quantify how important these forces are.

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Table 1: Trade Openness and Income, 1990-2011

	(1) CD	(2) CDCnstr	(3) FR	(4) Base	(5) BaseCnstr	(6) TFP	(7) IV-IMR	(8) IV-IMR1	(9) IV-Cap	(10) IV-Lab	(11) IV-All	(12) IV-All-Cnstr
A. Dep. Variable $\ln y_{j,t}$												
$\ln L_{j,t}$	0.332	0.495	0.264	0.283	0.323	0.236	0.212	0.212	0.231	0.314	0.269	0.377
	(0.041)**	(0.035)**	(0.038)**	(0.044)**	(0.037)**	(0.033)**	(0.045)**	(0.045)**	(0.044)**	(0.066)**	(0.060)**	(0.025)**
$\ln K_{j,t}$	0.460	0.505	0.322	0.425	0.432	0.524	0.507	0.507	0.474	0.442	0.459	0.452
	(0.035)**	(0.035)**	(0.050)**	(0.032)**	(0.039)**	(0.038)**	(0.046)**	(0.046)**	(0.045)**	(0.052)**	(0.050)**	(0.023)**
$\ln \sum_{j \neq i} X_{ij}$			0.264									
			(0.062)**									
$\ln(\widehat{\Pi_{j,t}^{\sigma-1}})$				-0.214	-0.245	-0.099	-0.089	-0.089	-0.099	-0.107	-0.085	-0.171
				(0.026)**	(0.020)**	(0.034)**	(0.029)**	(0.029)**	(0.029)**	(0.029)**	(0.030)**	(0.018)**
$TFP_{j,t}$						0.303	0.307	0.307	0.301	0.296	0.340	0.303
						(0.088)**	(0.097)**	(0.097)**	(0.099)**	(0.101)**	(0.081)**	(0.026)**
N	1606	1606	1579	1579	1579	1447	1380	1380	1380	1380	1322	1322
UnderId			16.519				156.439	156.921	158.530	153.488	147.666	
χ^2 p-val			(0.000)				(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	
Weak Id			14.782				510.75	345.439	213.842	229.508	153.673	
χ^2 p-val			(0.000)				(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	
Over Id							0.351	1.465	1.234	4.782	7.737	
χ^2 p-val							(0.554)	(0.481)	(0.745)	(0.189)	(0.102)	
B. Structural Parameters												
$\widehat{\alpha}$		0.505		0.540	0.572	0.582	0.557	0.557	0.525	0.495	0.501	0.545
		(0.035)**		(0.050)**	(0.046)**	(0.052)**	(0.054)**	(0.054)**	(0.054)**	(0.060)**	(0.053)**	(0.027)**
$\widehat{\sigma}$				4.674	4.084	10.114	11.282	11.180	10.128	9.385	11.812	5.847
				(0.580)**	(0.394)**	(2.817)**	(3.701)**	(3.632)**	(2.929)**	(2.547)**	(4.173)**	(0.620)**

Notes: This table reports estimates of the relationship between trade openness and income. All specifications include country and year fixed effects whose estimates are omitted for brevity. Columns (1) and (2) report estimates from an unconstrained and a constrained specification of the Cobb-Douglas production function. In column (3), we estimate a Frankel-and-Romer type of income regression. Columns (4) and (5), respectively, present unconstrained and constrained baseline estimates of our structural model. Column (6) introduces an additional control variable for technology. In column (7) we instrument for trade openness with our new instrument, and in column (8) we also add a version of the original Frankel-Romer instrument. Columns (9), (10), and (11) sequentially allow for endogeneous capital, labor, and TFP in addition to allowing for endogenous openness. Finally, in column (12) all regressors are treated as endogenous and we impose the structural restrictions of the model. In the bottom of panel A, we report UnderId χ^2 values, "weak identification" (WeakId) Kleibergen-Paap Wald F statistics (Kleibergen and Paap, 2006), and OverId χ^2 values when available. Note that the Kleibergen-Paap Wald test is appropriate when the standard error i.i.d. assumption is not met and the usual Cragg-Donald Wald statistic (Cragg and Donald, 1993), along with the corresponding critical values proposed by Stock and Yogo (2005), are no longer valid. This is true in our case, where the standard errors are either robust or bootstrapped. + $p < 0.10$, * $p < .05$, ** $p < .01$. See text for further details.

Table 2: Trade Openness and Income: Additional Instruments for Openness

	No Direct Internal Links			Labor Shares as Weights			Initial Output Levels as Weights		
	IV-IMR	IV-IMR1	IV-All-Cnstr	IV-IMR	IV-IMR1	IV-All-Cnstr	IV-IMR	IV-IMR1	IV-All-Cnstr
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
A. Dep. Variable $\ln y_{j,t}$									
$\ln L_{j,t}$	0.212	0.212	0.377	0.212	0.213	0.353	0.212	0.213	0.375
	(0.045)**	(0.045)**	(0.025)**	(0.045)**	(0.045)**	(0.023)**	(0.045)**	(0.045)**	(0.025)**
$\ln K_{j,t}$	0.507	0.507	0.452	0.507	0.506	0.465	0.507	0.506	0.448
	(0.046)**	(0.046)**	(0.023)**	(0.046)**	(0.047)**	(0.022)**	(0.046)**	(0.047)**	(0.023)**
$\ln(\widehat{\Pi_{j,t}^{\sigma-1}})$	-0.089	-0.089	-0.171	-0.092	-0.094	-0.182	-0.092	-0.094	-0.177
	(0.029)**	(0.029)**	(0.018)**	(0.031)**	(0.031)**	(0.018)**	(0.031)**	(0.031)**	(0.018)**
$TFP_{j,t}$	0.307	0.307	0.303	0.306	0.305	0.297	0.306	0.305	0.300
	(0.097)**	(0.097)**	(0.026)**	(0.096)**	(0.096)**	(0.026)**	(0.097)**	(0.096)**	(0.026)**
N	1380	1380	1322	1380	1380	1322	1380	1380	1322
UnderId	156.439	156.921		155.457	155.70		155.783	155.789	
χ^2 p-val	(0.000)	(0.000)		(0.000)	(0.000)		(0.000)	(0.000)	
Weak Id	510.75	345.439		337.725	231.167		327.377	227.193	
χ^2 p-val	(0.000)	(0.000)		(0.000)	(0.000)		(0.000)	(0.000)	
Over Id	0.351	1.465		1.542	1.679		3.710	4.001	
χ^2 p-val	(0.554)	(0.481)		(0.214)	(0.432)		(0.054)	(0.135)	
B. Structural Parameters									
$\widehat{\alpha}$	0.557	0.557	0.545	0.558	0.559	0.568	0.559	0.559	0.544
	(0.054)**	(0.054)**	(0.027)**	(0.054)**	(0.054)**	(0.026)**	(0.055)**	(0.054)**	(0.027)**
$\widehat{\sigma}$	11.282	11.180	5.847	10.852	10.610	5.485	10.845	10.583	5.662
	(3.701)**	(3.632)**	(0.620)**	(3.599)**	(3.439)**	(0.541)**	(3.595)**	(3.421)**	(0.585)**

Notes: This table reports estimates of the relationship between trade openness and income with three alternative sets of instruments. All specifications include country and year fixed effects whose estimates are omitted for brevity. Columns (1)-(3) replicate the estimates from columns (7), (8), and (12) of Table 1, which are obtained with an instrument for openness that explicitly removes the direct internal links in the multilateral resistance system. Columns (4)-(6) use an instrument that is constructed by solving the full multilateral resistance system but using labor shares instead of income shares as weights. Finally, the estimates in columns (7)-(9) are obtained with an instrument that is constructed by solving the full multilateral resistance system but using output shares from the initial year in our sample instead of current output shares as weights. In the bottom of panel A, we report UnderId χ^2 values, "weak identification" (WeakId) Kleibergen-Paap Wald F statistics (Kleibergen and Paap, 2006), and OverId χ^2 values when available. Note that the Kleibergen-Paap Wald test is appropriate when the standard error i.i.d. assumption is not met and the usual Cragg-Donald Wald statistic (Cragg and Donald, 1993), along with the corresponding critical values proposed by Stock and Yogo (2005), are no longer valid. This is true in our case, where the standard errors are either robust or bootstrapped. + $p < 0.10$, * $p < .05$, ** $p < .01$. See text for further details.

Table 3: Trade Openness and Capital Accumulation, 1990-2011

	(1) Base	(2) BaseCnstr	(3) IV-IMR	(4) IV-GDP	(5) IV-All	(6) IV-All-LSDV	(7) IV-All-Cnstr	(8) Diff-GMM
$\ln E_{j,t-1}$	0.011	0.016	0.012	0.007	0.010	0.083	0.061	0.047
	(0.003)**	(0.003)**	(0.004)**	(0.004)+	(0.004)**	(0.012)**	(0.004)**	(0.012)**
$\ln K_{j,t-1}$	0.984	0.984	0.983	0.986	0.983	0.948	0.939	0.934
	(0.003)**	(0.003)**	(0.003)**	(0.003)**	(0.003)**	(0.008)**	(0.004)**	(0.009)**
$\ln P_{j,t-1}$	-0.052	-0.016	-0.047	-0.064	-0.065	-0.043	-0.061	-0.164
	(0.012)**	(0.003)**	(0.013)**	(0.013)**	(0.013)**	(0.026)+	(0.004)**	(0.083)*
N	1684	1684	1602	1602	1602	1602	1602	1684
UnderId			197.088	197.406	197.512	255.859		
χ^2 p-val			(0.000)	(0.000)	(0.000)	(0.000)		
Weak Id			6899	4007	3190	243.210		
χ^2 p-val			(0.000)	(0.000)	(0.000)	(0.000)		
OverId			0.388	4.559	2.921	1.553		3919
χ^2 p-val			(0.533)	(0.103)	(0.232)	(0.460)		(0.000)
AR(1)								-1.210
χ^2 p-val								(0.226)
AR(2)								-0.412
χ^2 p-val								(0.680)

Notes: This table reports estimates of the relationship between trade openness and capital accumulation. Column (1) reports results from a baseline OLS estimator. In column (2), we impose the structural constraints of our theory. Columns (3), (4) and (5) report IV estimates, where trade openness (i.e., the inward multilateral resistances), expenditure, and capital are sequentially treated as endogenous. Column (6) reports Least Squares Dummy Variable (LSDV) panel estimates with all regressors being treated as endogenous. In addition to treating all regressors as endogenous and using an LSDV estimator, the specification in column (7) also imposes the structural restrictions of our theory. Finally, the estimates in column (8) implements a dynamic panel-data difference GMM estimator. Robust standard errors in parentheses. + $p < 0.10$, * $p < .05$, ** $p < .01$. See text for further details.

Table 4: Parameter Estimates

Recovered From	**Parameter**	**Min. Value**	**Max. Value**
Trade	$\widehat{\eta}_1$	0.827	
		(0.135)**	
	$\widehat{t}_{ij}$	1.184	132.7
Income	$\widehat{\alpha}$	0.495	0.582
		(0.060)**	(0.052)**
	$\widehat{\sigma}$	4.084	11.282
		(0.394)**	(3.701)**
Capital	$\widehat{\delta}$	0.016	0.061
		(0.003)**	(0.004)**
Cons. Discount	$\widehat{\beta}$	0.98	

Notes: This table reports the values for parameters in our model. Panel "Trade" reports the RTA estimate (top row), and the minimum and maximum values for bilateral trade costs (bottom row). Panel "Income" reports the minimum and the maximum values for the capital shares (top row), and for the trade elasticity (bottom row), from panel B of Table 1. Panel "Capital" reports the minimum and the maximum values of the capital depreciation rates from the constrained structural regressions from Table 3. Finally, in panel "Cons. Discount" we report the estimate of the consumer discount factor, which we borrow from the literature. Robust standard errors, when available, are in parentheses. + $p < 0.10$, * $p < .05$, ** $p < .01$.

Table 5: Welfare Effects of NAFTA and Globalization

	NAFTA				Globalization			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Country	Cond. GE	Full Static GE	Full Dynamic GE, SS	Full Dynamic GE, trans.	Cond. GE	Full Static GE	Full Dynamic GE, SS	Full Dynamic GE, trans.
AGO	-0.034	-0.059	-0.093	-0.079	1.510	2.998	6.489	4.804
ARG	-0.007	-0.012	-0.019	-0.016	0.467	0.939	2.095	1.533
AUS	-0.007	-0.013	-0.021	-0.018	0.632	1.277	2.866	2.091
AUT	-0.005	-0.009	-0.015	-0.013	2.244	4.477	9.804	7.217
AZE	-0.005	-0.010	-0.015	-0.013	0.607	1.222	2.733	1.997
BEL	-0.012	-0.021	-0.032	-0.027	4.140	8.072	16.870	12.639
BGD	-0.003	-0.005	-0.009	-0.008	0.221	0.450	1.029	0.746
BGR	-0.001	-0.002	-0.004	-0.003	0.848	1.715	3.871	2.818
BLR	0.000	-0.001	-0.002	-0.001	1.166	2.316	5.021	3.715
BRA	-0.006	-0.011	-0.019	-0.016	0.298	0.603	1.364	0.992
CAN	2.927	5.859	12.899	9.572	2.050	4.029	8.527	6.368
CHE	-0.017	-0.029	-0.044	-0.038	2.779	5.492	11.787	8.745
CHL	-0.027	-0.048	-0.076	-0.064	1.140	2.276	4.984	3.672
CHN	-0.008	-0.015	-0.024	-0.020	0.427	0.866	1.966	1.428
COL	-0.015	-0.027	-0.043	-0.036	0.318	0.642	1.447	1.055
CZE	-0.002	-0.003	-0.006	-0.005	1.866	3.747	8.313	6.089
DEU	-0.008	-0.014	-0.022	-0.019	1.546	3.126	7.031	5.125
DNK	-0.006	-0.011	-0.019	-0.016	2.077	4.166	9.217	6.758
DOM	-0.023	-0.041	-0.067	-0.056	0.514	1.029	2.272	1.669
ECU	-0.018	-0.032	-0.052	-0.044	0.769	1.542	3.408	2.502
EGY	-0.002	-0.004	-0.007	-0.006	0.339	0.688	1.565	1.136
ESP	-0.005	-0.009	-0.014	-0.012	1.050	2.123	4.789	3.486
ETH	-0.001	-0.002	-0.003	-0.002	0.134	0.271	0.616	0.448
FIN	-0.008	-0.015	-0.024	-0.020	1.994	3.994	8.817	6.471
FRA	-0.005	-0.009	-0.015	-0.013	1.204	2.443	5.541	4.025
GBR	-0.010	-0.017	-0.028	-0.023	1.003	2.049	4.708	3.403
GHA	-0.004	-0.008	-0.013	-0.011	0.375	0.764	1.748	1.266
GRC	-0.001	-0.002	-0.003	-0.003	0.584	1.189	2.719	1.969
GTM	-0.031	-0.056	-0.090	-0.076	0.519	1.042	2.313	1.695
HKG	-0.012	-0.022	-0.035	-0.030	1.780	3.535	7.644	5.661
HRV	-0.001	-0.002	-0.004	-0.003	0.498	1.013	2.315	1.676
HUN	-0.003	-0.005	-0.009	-0.008	1.879	3.769	8.347	6.118
IDN	-0.003	-0.005	-0.009	-0.007	0.477	0.972	2.216	1.607
IND	-0.002	-0.004	-0.006	-0.005	0.185	0.377	0.867	0.626
IRL	-0.032	-0.055	-0.081	-0.071	3.930	7.672	16.060	12.028
IRN	0.000	-0.001	-0.001	-0.001	0.362	0.732	1.651	1.202
IRQ	-0.018	-0.033	-0.052	-0.044	0.990	1.978	4.341	3.196
ISR	-0.033	-0.058	-0.093	-0.078	1.479	2.968	6.568	4.819
ITA	-0.004	-0.007	-0.012	-0.010	0.952	1.935	4.405	3.195
JPN	-0.009	-0.016	-0.025	-0.021	0.400	0.811	1.842	1.338
KAZ	-0.004	-0.007	-0.011	-0.009	0.854	1.709	3.760	2.766
KEN	-0.001	-0.002	-0.004	-0.003	0.184	0.374	0.847	0.616
KOR	-0.017	-0.031	-0.049	-0.041	1.130	2.266	5.011	3.678
KWT	-0.005	-0.010	-0.017	-0.014	0.921	1.850	4.101	3.008
LBN	-0.004	-0.007	-0.011	-0.009	0.801	1.620	3.652	2.660
LKA	-0.004	-0.008	-0.013	-0.011	0.358	0.728	1.659	1.204
LTU	-0.006	-0.010	-0.016	-0.014	0.928	1.879	4.244	3.089
MAR	-0.004	-0.007	-0.011	-0.009	0.648	1.313	2.970	2.160
MEX	1.764	3.532	7.778	5.748	1.303	2.587	5.594	4.143
MYS	-0.032	-0.056	-0.087	-0.074	2.849	5.627	12.007	8.936
NGA	-0.029	-0.051	-0.081	-0.069	1.615	3.203	6.915	5.124
NLD	-0.009	-0.016	-0.026	-0.022	2.937	5.835	12.637	9.343
NOR	-0.037	-0.065	-0.097	-0.084	2.093	4.194	9.266	6.798
NZL	-0.010	-0.018	-0.030	-0.025	0.974	1.954	4.326	3.174
OMN	-0.005	-0.009	-0.015	-0.012	1.305	2.601	5.680	4.190
PAK	-0.002	-0.003	-0.006	-0.005	0.168	0.343	0.783	0.567
PER	-0.026	-0.046	-0.073	-0.062	0.634	1.274	2.835	2.076
PHL	-0.008	-0.014	-0.023	-0.020	0.634	1.285	2.907	2.115
POL	-0.001	-0.002	-0.004	-0.003	0.965	1.962	4.472	3.242
PRT	-0.003	-0.005	-0.008	-0.007	1.204	2.430	5.459	3.980

Continued on next page

Table 5 – *Continued from previous page*

Country	NAFTA Cond. GE	NAFTA Full Static GE	NAFTA Full Dynamic GE, SS	NAFTA Full Dynamic GE, trans.	Globalization Cond. GE	Globalization Full Static GE	Globalization Full Dynamic GE, SS	Globalization Full Dynamic GE, trans.
QAT	-0.003	-0.006	-0.011	-0.009	1.930	3.827	8.253	6.118
ROM	-0.001	-0.003	-0.004	-0.004	0.837	1.695	3.838	2.790
RUS	-0.001	-0.002	-0.004	-0.003	0.330	0.671	1.528	1.108
SAU	-0.010	-0.018	-0.030	-0.025	0.890	1.786	3.957	2.903
SDN	-0.002	-0.003	-0.005	-0.005	0.444	0.893	1.988	1.455
SER	-0.001	-0.001	-0.002	-0.002	0.391	0.793	1.806	1.310
SGP	-0.042	-0.072	-0.105	-0.092	5.404	10.359	20.856	15.856
SVK	-0.001	-0.002	-0.004	-0.003	2.244	4.475	9.792	7.211
SWE	-0.008	-0.015	-0.025	-0.021	2.202	4.409	9.720	7.137
SYR	-0.003	-0.005	-0.008	-0.007	1.316	2.636	5.822	4.274
THA	-0.009	-0.016	-0.026	-0.022	0.994	2.004	4.475	3.272
TKM	0.000	-0.001	-0.001	-0.001	0.587	1.178	2.613	1.916
TUN	-0.001	-0.002	-0.004	-0.003	0.975	1.967	4.415	3.220
TUR	-0.002	-0.004	-0.006	-0.005	0.519	1.056	2.409	1.746
TZA	-0.001	-0.002	-0.004	-0.003	0.295	0.597	1.345	0.980
UKR	-0.001	-0.002	-0.003	-0.003	0.607	1.219	2.703	1.982
USA	0.316	0.637	1.428	1.031	0.358	0.736	1.710	1.231
UZB	0.000	-0.001	-0.001	-0.001	0.232	0.468	1.048	0.766
VEN	-0.024	-0.043	-0.070	-0.059	0.637	1.277	2.825	2.074
VNM	-0.006	-0.012	-0.020	-0.016	0.984	1.984	4.438	3.244
ZAF	-0.005	-0.009	-0.015	-0.012	0.575	1.164	2.624	1.911
ZWE	0.000	-0.001	-0.002	-0.001	0.184	0.371	0.835	0.608
World	0.171	0.344	0.770	0.562	0.779	1.568	3.500	2.559
NAFTA	0.630	1.265	2.806	2.056				
ROW	-0.007	-0.013	-0.021	-0.018				

Notes: This table reports results from our NAFTA and globalization counterfactuals. Column (1) lists the country abbreviations. Columns (2) to (5) report percentage changes in welfare for three different scenarios. The "Cond. GE" scenario takes the direct and indirect trade cost changes into account but holds GDPs constant. The "Full Static GE" scenario additionally takes general equilibrium income effects into account. The "Full Dynamic GE" scenario adds the capital accumulation effects. For the latter, we report results that do not take transition into account (in column (4)) and welfare gains that take transition into account (in column (5)). Columns (6) to (9) report percentage changes in welfare for the same four scenarios for our globalization counterfactual. See text for further details.

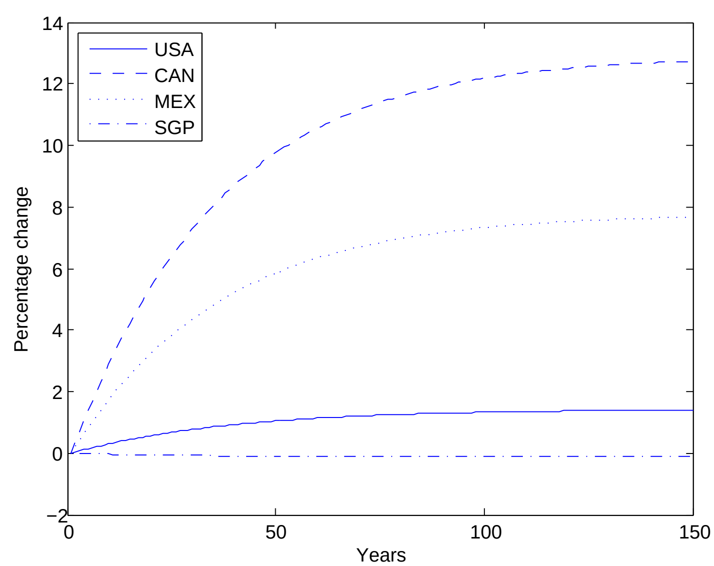

Figure 1: On the Transitional Effects of NAFTA: Capital Stocks