Trapped Factors and China's Impact on Global Growth

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Abstract

In response to a recent increase in Chinese import competition, European firms increased their innovation. We present and then rationalize these cross-sectional patterns using "trapped factors" at the micro level within a stylized equilibrium model of product-cycle trade and growth. Trade integration of the magnitude observed between the OECD and low-wage nations as a whole can considerably increase the long-run growth rate and welfare. In the short-run exposed firms devote trapped factors to increased innovation, leading both to increased innovation at these firms in the cross section as well as to a small amount of extra transitional growth overall. China alone accounts for half of the dynamic trade gains.

Keywords: innovation, trade, China, endogenous growth

JEL Classification: D92, E22, D8, C23.

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1 Introduction

At the time of writing there is a substantial populist backlash against free trade in richer countries like the US, especially trade with China which is held responsible for job losses and slow wage growth. Ever since Adam Smith published *The Wealth of Nations*, economists have debated the sign and magnitude of the gains from trade. Participants in these debates have long recognized that the dynamic gains from trade could be quite large. Recent evidence from the empirical micro-literature suggests that trade can indeed have a large positive impact on innovation and productivity.[1] Likewise, some reduced form macro-empirical estimates also suggest that trade can have a large impact on the level of national income or its rate of growth.[2] In this paper, we present and use a simple model in the endogenous growth tradition to argue that the gains from trade can be large when innovation responds to trade. Our model is purposefully distinct from the widely used class of quantitative trade models incorporating static gains from trade, which compute gains relying on a different set of mechanisms and liberalization experiments.[3]

Before detailing the model, we first introduce empirical evidence exploiting a micro-level database of firm patenting behavior and trade flows showing that firms in Europe that faced more direct competition from China's low-wage exports undertook bigger increases in product innovation even during this period of duress.[4] To match this empirical response, we craft a model in which firms choose how much to invest in developing new products and processes. In the spirit of models of endogenous growth,[5] the model requires that all increases in productivity come from these firm-level investments in innovation. As a result, we can trace the effects that an incremental change in trade policy has on innovation through to the implied change in the aggregate rate of growth, taking full account of general equilibrium interactions. The model confirms the intuition that the dynamic gains from trade can be large.

The challenge in capturing our micro-empirical evidence is to explain why a firm that is more exposed to import competition from China - an apparent negative demand shock which also leads to relative sales declines in our data - has a bigger incentive to develop new goods. We show

[1]See for example Pavcnik (2002) on Chile, Bernard et al. (2006) for the US, Amiti and Konings (2007) on Indonesia, Goldberg et al. (2010) looking at imports in India, Lileeva and Trefler (2010) on export induced upgrading in Canada, Aw et al. (2011) on Taiwan, De Loecker (2011) on Belgium, Bustos (2011) on Argentina, and Medina (2018) on Peru.

[2]See, for example, Frankel and Romer (1999), or case studies such as Romer (1992) on the effect of an Export Processing Zone in Mauritius, Bernhofen and Brown (2005) on post-Meiji Japan, Trefler (2004) on CAFTA, Feyrer (2009) on the Suez Canal, or Irwin (2005) on the Jefferson embargo.

[3]For example, Costinot and Rodríguez-Clare (2015) calculate US gains of around 2% relative to autarky. A multi-sector model can increase these to about 4%, and Eaton and Kortum (2012) have an estimate of 5%. The welfare calculations in Costinot and Rodríguez-Clare (2015) are based on the trade elasticity combined with the import share of GDP, echoing the strategy emphasized by Arkolakis et al. (2012). Melitz and Redding (2015) argue a heterogeneous firm model has larger welfare effects. In each of these cases, larger welfare effects of trade can be generated by allowing for traded intermediates or by focusing on more open economies than the US.

[4]Our results relate to and build on previous work in Bloom et al. (2015) but use an alternative identification strategy and broader industry coverage.

[5]See Romer (1990), Romer (1987), Aghion and Howitt (1992), and Grossman and Helpman (1991) for example.

within our model that this pattern is precisely what one would expect if factors of production are temporarily "trapped" within firms due to moving costs. If, for example, skilled engineers or managers develop firm-specific or industry-specific knowledge which are expensive or less useful to immediately deploy elsewhere, a negative demand shock to a good they helped produce leaves them in the firm but reduces their opportunity cost. Under this scenario, the firm innovates after the trade shock not just because the value of a newly designed product has gone up for the market as a whole, but also because the opportunity cost of designing and producing the product have gone down within that firm. This interpretation of trapped factors is consistent with some existing empirical evidence that firms shift resources out of activities that compete with imports from low-wage countries (Bernard et al., 2006). The idea is also born out in many case studies of international trade in which firms respond to import competition from a low-wage nation by developing an entirely new type of good that will be less vulnerable to this type of competition.

In addition to this trapped-factor effect of trade on innovation, the model allows for the independent effect that a more integrated world market has on the steady-state growth rate (a "market size" effect). A reduction in trade barriers increases purchasing power in the South, which increases the profit that a Northern firm can earn from sales there. In contrast to the effect of trapped-factors on innovation, which arises only at firms that face direct competition from low-wage imports, this increase in potential profits causes an increase in the rate of innovation at all Northern firms, and is therefore harder to identify from micro-data. It is an incremental version of the scale effect on growth that has been examined in models of trade with endogenous growth based on a binary comparison of two isolated economies versus a single fully integrated economy (Grossman and Helpman, 1990; Rivera-Batiz and Romer, 1991). We build a model analyzing this mechanism which is flexible enough to be used in a numerical calibration. Naturally, our model allows for a comparison across equilibria with a continuum of degrees of openness.

In our product-cycle model, innovation in the North produces new intermediate inputs that are used by firms in both the North and the South. In a steady-state equilibrium, trade barriers prevent factor-price equalization, so goods produced in the South have an absolute cost advantage.

In this environment, we perform a calibrated numerical exercise by studying a shock to the level of integration across the two economies. In performing this suggestive experiment, we are solely focused on understanding the potential scale or importance of innovation-based or dynamic gains from trade. We find in this exercise that the increased global integration of the OECD with all low-wage countries that took place during the decade around China's accession to the WTO increases the long-run rate of growth in the OECD from 2.0% per year to almost 2.6% per year. Of this increase, approximately one half, or 0.3%, can be attributed to China by alone.

Of course, small increases in growth can generate substantial improvements in welfare. This increase in the rate of growth from trade with the South has a welfare effect that would be equivalent to increasing consumption by 26%. Of this increase in consumption, 23% is from the increased profitability of innovation and 3% is from the trapped-factor effect. Although the trapped-factors mechanism has a smaller long-run welfare effect, it gains importance for our analysis in two ways. First, the trapped factors mechanism generates heterogeneity in the incentives for innovation at firms exposed to trade liberalization in the cross-section, directly rationalizing our empirical results and linking trade competition to innovation. Second, the gains from trapped factors may have extra salience for policy because the effect is front-loaded. Over the first decade after the trade shock, the trapped-factor effect on the rate of growth is similar in magnitude to the market-size effect. For trade with all low-wage countries, the trapped-factor effect increases the rate of growth by an additional 0.4% per year (i.e. the combined effect of the market size and trapped factors effects raises the growth rate from 2.0% to 3.0% per year) in the first decade after the liberalization.

We view the magnitudes of the dynamic gains from trade in our numerical exercise as suggestive that quantitative researchers in trade should focus future attention on innovation or dynamic mechanisms. While traditional static quantitative trade models often deliver magnitudes for the gains from trade smaller than the ones we uncover, the two sets of results are not strictly comparable. To highlight the potential importance of dynamics gains, we purposefully abstract from a rich range of frictions and mechanisms employed in the static quantitative trade literature. A fuller and more detailed quantitative analysis in future would likely benefit from employing our dynamic mechanism within a richer static quantitative trade framework.

We focus purely on trade effects rather than business cycle fluctuations or transitional growth in developing economies. We therefore calibrate based on aggregate frontier data bracketing the global crisis of 2008-9, and we leave to future work the possibility that such large cyclical fluctuations may have long-lasting effects on income. Given the potentially large positive effects on innovation we find from integration with emerging economies like China, our findings strike a more positive note on the future of frontier growth than, say, Gordon (2012).

Our model tying trade liberalization to dynamics gains through innovation includes features drawn prominently from the literature on endogenous growth in macroeconomics. We link to a burgeoning strand of recent work in this area at the intersection of macroeconomics and trade with examples including Atkeson and Burstein (2010), Perla et al. (2015), Sampson (2016), Buera and Oberfield (2016), and Costantini and Melitz (2008) We do so distinctively by tying the dynamics effects of trade liberalization to classic product-cycle dynamics reflecting the asymmetry in the costs of Northern and Southern goods. Our model and numerical statements below of course abstract from a range of interesting effects of liberalization considered in the trade literature, which we briefly summarize.

First, by design we model trade exposure in a rich way on the production side of the economy but abstract from meaningful labor market dynamics or heterogeneous impacts at the worker level. A range of interesting papers including Dix-Carneiro (2014), Artuç et al. (2010), Caliendo et al. (Forthcoming), and Traiberman (Forthcoming) dynamically model frictions such as occupational or industry or regional adjustment barriers preventing flexible short-run adjustment of workers to trade shocks. The dynamic analyses in these papers generally reveal that labor reallocation frictions may matter quantitatively and lead to winners and losers after a trade shock. A model incorporating such frictions together with our dynamic innovation-based gains from trade is beyond the scope of our paper but likely would moderate our results somewhat.

Second, we abstract from a range of specialized features in quantitative trade models that often deliver larger gains from trade, e.g., multiple qualitatively distinct production sectors, trade in intermediates, or multi-country firms. See Costinot and Rodríguez-Clare (2015) or Caliendo and Parro (2015) for summaries of the effect of these extensions. See work by Blaum et al. (2018) that emphasizes intermediate trade in particular, and see papers such as Helpman et al. (2004), Antràs and Yeaple (2014), or Garetto (2013) for analyses of the impact of multinational production. Although incorporation of such factors is beyond the scope of this paper, a broad reading of the research in trade suggests that such intermediate goods trade may matter meaningfully for the gains from trade.

Our paper connects not just to the general literature cited above on the welfare effects of trade, but also on those papers that look specifically at the impact of trade with China. See for example, Hsieh and Ossa (2016), Autor et al. (2013), Pierce and Schott (2016), Khandelwal et al. (2013), Manova and Zhang (2012), or Medina (2018). Because of concern about increased inequality, an older literature on the distributional effects of trade that arise when labor is industry-specific (Mussa, 1974) is generating renewed interest. In such models, the gains from trade for some groups are offset by welfare losses for others. The optimistic conclusions from our analysis of the gains from trade need to be tempered if a trade liberalization increases inequality. Relative to the existing literature, in which specific factors do not imply efficiency gains, in our second-best model, trapped factors can generate additional welfare gains when there are unexpected increases in trade.

The model of innovation spurred by a reduction in the opportunity cost of the inputs used in innovation is reminiscent of the old idea that trade competition reduces X-inefficiency. We generate such effects without appealing to the type of principal-agent models (Schmidt, 1997) that De Loecker and Goldberg (2013) have recently questioned. Finally, our structure, in which firms take advantage of a negative shock by investing in innovation, is similar in spirit to classic business cycle theories about the "virtues of bad times" described by Aghion and Saint-Paul (1998) or Hall (1991). More recently, Bernard and Okubo (2016) investigate unusually granular Japanese data at the firm-product level. They find, entirely consistent with the basic trapped factors or opportunity cost mechanism, that switching by firms to new products is concentrated during business cycle downturns.

The road map to the rest of the paper is as follows. We start by introducing empirical evidence in Section 2 which links trade liberalization and innovation to our notion of trapped factors. Section 3 presents our baseline model of trade and long-term growth, laying out our framework for trade shocks in fully mobile and trapped factors cases. Section 4 moves on to the numerical exercise, and Section 5 offers some extensions and robustness tests. Section 6 concludes. A set of online appendices contain many technical details of the theoretical proofs (A), the data and model calibration (B), the model solution method (C), an extension to a semi-endogenous growth approach (D), an extension to an alternative R&D cost function (E), and an extension to an economy with Southern innovation (F).

2 Trade Shocks and Innovation in the Data

In the last few decades, developed economies have dramatically liberalized trade with developing nations with much lower wages. To illustrate the magnitude of this change, we classify nations into non-OECD and OECD groups. Imports from non-OECD group into the OECD group more than doubled from 3.5% of OECD GDP in 1994 to 8.4% in 2014. In Figure 1, which is constructed using a mix of OECD and Penn World Tables data described in Appendix B, the black line with circle markers plots this import-to-GDP ratio for each year in the period. After increasing sharply in the wake of Chinese WTO accession in 2001, low-cost imports dipped and then stabilized at a higher level after the Great Recession. China's individual role seems particularly important. In the blue line with triangles, Figure 1 displays the ratio of Chinese imports to OECD GDP over the same period. Chinese imports grew from 0.5% to 3.0%, representing about half of the total increase in low-wage imports into the developed world. We conclude that not only was the recent trade liberalization toward low-cost countries large but also that any analysis of this liberalization must give central importance to understanding the effects of increased trade with China on the world economy.

Within individual firms and industries in rich nations, one might expect that the entry of competitors like China with lower costs and tremendous scale would lead to convulsive effects. Empirically, firms surviving the onslaught of import competition do indeed exhibit substantive changes in their activities. Perhaps surprisingly, however, firms appear to shift towards innovation. In Italy, Bugamelli et al. (2010) show that a range of manufacturers from ceramic tiles to women's clothing switched to more innovative high-end products in response to rising low-wage competition. Relatedly, Freeman and Kleiner (2005) showed in a case study that US shoe manufacturers switched from making low-cost mass market shoes to innovative products when faced with Chinese competition.

We analyze the innovative behavior of European firms more systematically and exploit a database of European manufacturing firms with the following information: 1) firm-level accounting statements spanning 11 countries from 1995-2005 drawn from the Bureau van Dijk Amadeus dataset, 2) matched firm-level patent data from the European Patent Office, 3) disaggregated trade flows at the country by four-digit industry level from the UN Comtrade database, and 4) associated US production data at the four-digit industry level from the NBER manufacturing database. The first two sources are drawn from the database constructed by Bloom et al. (2015).

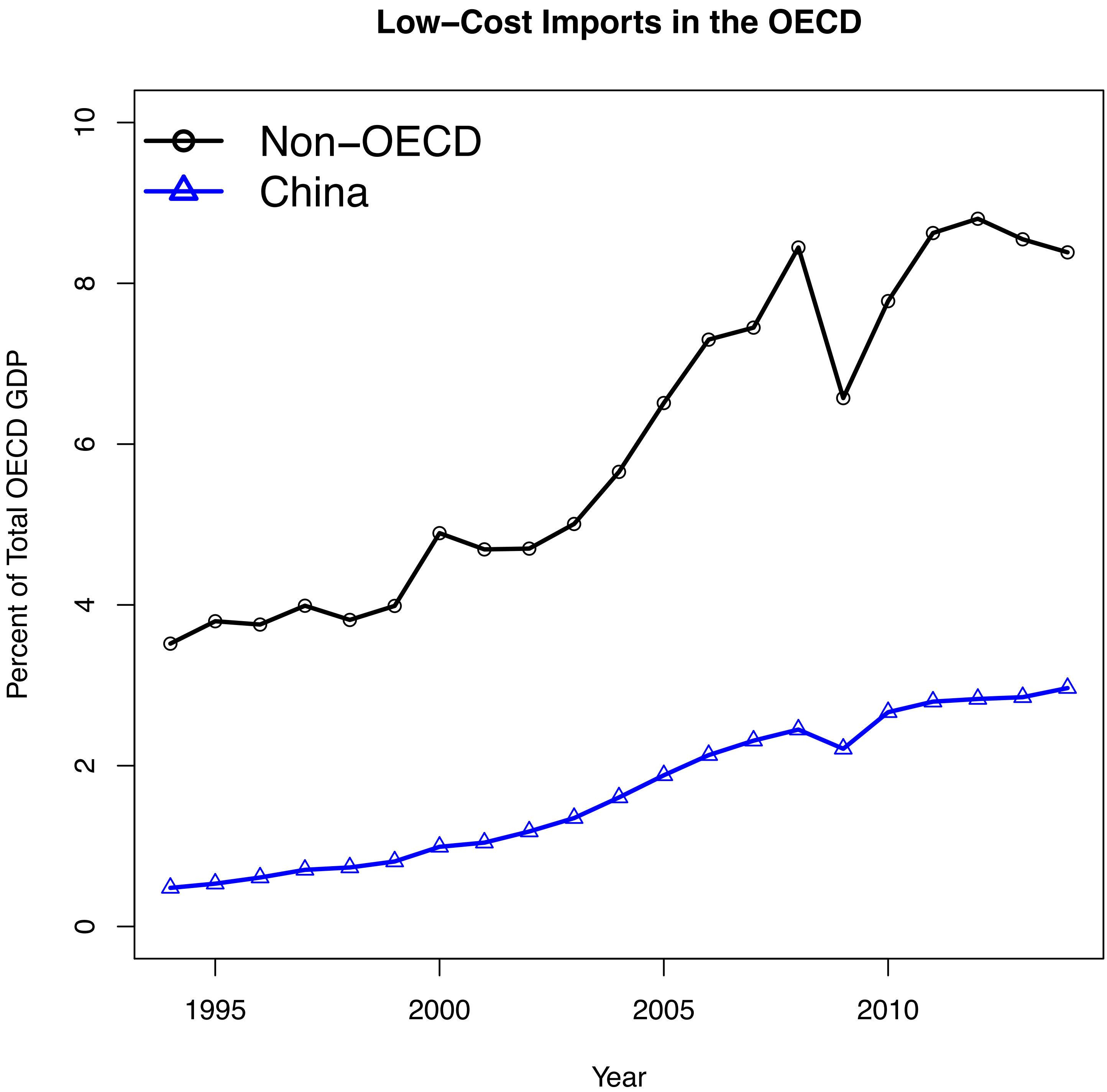

Figure 1: Import Ratios are Increasing

Note: Non-OECD and Chinese imports into OECD countries are from the OECD-STAN database as available in July 2017. Chinese import data is directly available, and non-OECD imports are imputed as the difference between world imports and imports from other OECD members in a given year. The normalizing GDP measure for the OECD is computed from the Penn World Tables version 9.0 and equals the sum of GDP for all OECD members in a given year. The Chinese imports to OECD GDP ratio in 1994 is 0.50% and in 2014 is 3.0%. The total non-OECD imports to OECD GDP ratio in 1994 is 3.5% and in 2014 is 8.4%.

All together, these data sources lead to a panel including innovation and trade measures for around 7,000 firms spanning around 1,000 country-industry pairs and containing about 25,000 firm-year observations. For more details, see Appendix B.

Column 1 of Panel A in Table 1 presents an OLS regression of innovation as measured by the five-year change in patenting $\Delta \ln(\text{PATENTS})_{ijkt}$ in firm i, industry j, country k, and year t on the corresponding five-year change in Chinese imports $\Delta \text{ IMP}^{CH}_{jkt}$, measured as the ratio of Chinese imports to total production in the same industry by country cell. We also control for country-year dummies:

$$\Delta \ln(\text{PATENTS})_{ijkt} = \alpha \Delta \text{IMP}^{CH}_{jkt} + f_{kt} + \nu_{ijkt}$$

The resulting value of $\hat{\alpha}$ is positive and precisely estimated. Firms in European industries exposed more to increased Chinese import competition increase patenting more than firms in other industries in the same country and year. However, a range of potentially confounding factors complicate the interpretation of this estimate. In particular, if there are local unobserved shocks to the profitability of a particular industry-European country pair that systematically link to Chinese import demand, then such shocks could drive both trade flows and innovative patenting behavior over the horizons we consider. In light of this concern, we follow a recently popularized instrumental variables strategy from Autor et al. (2013), instrumenting the change in Chinese imports into a particular European country-industry cell using the symmetrically measured change in Chinese imports into the same four-digit industry cell in the US. To the extent that local import demand shocks are in fact local to a particular nation-industry pair, this strategy recovers the effect of Chinese imports on European patenting behavior. Column 2 reports that Chinese imports into the US are indeed strongly predictive of flows into Europe in first-stage estimates, and a positive and precise impact of Chinese imports on European patenting results in the second stage. At this point, at least one natural concern remains: longer-term trends in both import flows and innovation behavior in an industry might be correlated but otherwise unrelated, spuriously generating a link between import competition and patenting. So in Column 3 we add two-digit sector level dummies to the specification above, exploiting only variation in patenting and import flows away from the overall trend in a particular sector. We uncover that a 10% increase in Chinese imports leads to a 2.2% increase in patenting at European firms.

Systematically, increased low-cost import competition leads to higher innovation in Europe, a result made more remarkable by the fact that exposed firms suffer meaningfully along other dimensions from the increased competition. Panel B replaces the five-year patenting change with firm sales growth. The baseline OLS associations in Column 1 are ambiguous, potentially reflecting underlying unobserved shocks driving import competition and sales growth simultaneously. So Columns 2 and 3 implement IV specifications and add controls for sectoral trends, respectively. In Column 3, we see that the same 10% increase in Chinese imports leads to a decline of 6.3% in sales growth.

Table 1: Chinese Import Growth, Patenting and Firm Sales

Panel A: Patents

	(1)	(2)	(3)
Estimation Method	OLS	IV	IV
Change in Chinese Imports	0.0952***	0.303***	0.222**
	(0.0310)	(0.0763)	(0.105)
First-Stage F-Statistic		16.1	19.4
Sector Trends			X
Years	1996-2005	1996-2005	1996-2005
Industry-Country Clusters	910	910	910
Firms	7,006	7,006	7,006
Firm-Year Observations	24,926	24,926	24,926

Panel B: Sales

	(1)	(2)	(3)
Change in Chinese Imports	0.001	-0.473***	-0.631***
	(0.035)	(0.161)	(0.235)
First-Stage F-Statistic		20.1	16.1
Sector Trends			X
Years	1996-2005	1996-2005	1996-2005
Industry-Country Clusters	885	885	885
Firms	6,119	6,119	6,119
Firm-Year Observations	20,722	20,722	20,722

Notes: *** denotes 1%, ** 5%, and * 10% significance. Standard errors clustered by country x 4-digit SIC industry and year (in parentheses). Country-year effects in all models. Firm-level patenting per worker from the European Patent Office. Firm sales from BvD Amadeus. Dependent variables each in five-year percent changes. Chinese import growth in Europe by country-industry-year from UN Comtrade for Austria, Germany, Denmark, Spain, Finland, France, Great Britain, Ireland, Italy, Norway, Sweden. The instrumental variable for all models is Chinese import growth into the US industry-year cell. Trade flows normalized by 1996 production in the country-industry cell, from Eurostat's Prodcom or the NBER manufacturing database. Sectoral trends specifications include 2-digit SIC sector dummies.

To summarize, in the face of a surge in Chinese import competition, European firms experience sales declines and increase their patenting considerably. The *cross-sectional* impact of trade exposure on patenting raises the possibility that trade liberalization can link to innovation and dynamic gains from trade liberalization due to higher growth *on average*. Our theoretical model of trade and growth delivers exactly this sort of information about the total gains from trade, relying on classic insights from the endogenous growth literature. However, the empirical results also pose a challenge for theory, since the model must be rich enough to explain why firms that are more exposed to an onslaught of import competition patent in greater numbers than less exposed firms. Our trapped factors mechanism added to the model below provides a link to the cross-sectional variation in Table 1, interpreting higher innovation as the result of the reallocation of trapped resources - talent, specialized knowledge, organizational capital, specialized equipment, etc - within the firm away from lost production opportunities and towards the creation of new ideas and innovation.

Before moving onto the model description and quantitative experiments, we first pause to discuss the link between the results in Table 1 and two other recent sets of empirical results in this area. Our results build on and extend the dataset constructed in Bloom et al. (2015), who exploit idiosyncratic variation in Chinese textiles imports into Europe due to the removal of disaggregated quotas on China previously embedded in the Multi Fibre Agreement. Bloom et al. (2015) find that affected firms increased their patenting in response to Chinese imports. We expand that earlier analysis to study the European manufacturing sector as a whole by exploiting an alternative identification strategy based on our use of imports from China into the same US industry as an instrumental variable. As noted above, we build on work by Autor et al. (2013) which introduces and exploits a symmetric identification strategy to study the impact of China on local US employment. We confirm that in the European context, trade flows into other developed nations continue to provide a powerful source of variation. We also link directly to Autor et al. (2016), who find that patenting at US manufacturing firms declines in the face of increased Chinese competition. We view our results as complementary, both confirming the strength of a similar identification strategy in the European context but also revealing the quantitative importance of controlling for sectoral trends, a point usefully emphasized in that paper. To explain the difference between their results and those in Bloom et al. (2015), Autor et al. (2016) speculate that US manufacturing industries may start from a higher level of competitiveness relative to China. In models such as the one in Aghion et al. (2005), such differences can cause opposite reactions in innovation. Our empirical results are entirely consistent with Autor et al. (2016)'s interpretation. However, we craft our distinct model below to match the case of a importing nation starting at a stronger competitive disadvantage, apparently more in line with the European experience. We turn to this task now.

3 A Model of Trade and Growth

In this section we first introduce the basic structure of the model for a closed economy. This lets us describe the technology and highlight the key equation in the model. It characterizes the rate of growth of the variety of inputs, which can also be interpreted as the rate of growth of patents or new designs. We then introduce product-cycle trade into the model between an innovating Northern economy and a low-cost Southern economy. Although in the initial introduction of the model, which characterizes equilibrium along a balanced growth path, we omit discussion of the costs that can trap factors in firms, we finally bring them into a description of trade shocks at the end of this section.

3.1 Technology

There are two types of inputs in all types of production, human capital and a variety of produced intermediate inputs. At any date, these inputs can be used in three different productive activities: producing final consumption goods, producing new physical units of the intermediate inputs that will be used in production in the next period, and producing new designs or patents. We assume that the two types of inputs are used with the same factor intensities in these three activities, so we can use the simplifying device of speaking of the production first of final output in a final goods sector, and then the allocation of final output to the production of consumption goods, intermediate inputs, or new patented designs. We can also speak of final output as the numeraire, with the understanding that it is in fact the bundle of inputs that produces one unit of final output that is actually the numeraire good.

With this convention, we can write final output Y_t in period t, as the following function of human capital H and intermediate goods $x_{jt},$ where j is drawn from the range of intermediate inputs that have already been invented, $j \in [0, A_t]$:

$$Y_t = H^{\alpha} \int_0^{A_t} x_{jt}^{1-\alpha} dj$$

Using the convention noted above, we can speak of firms in period t devoting a total quantity Z_t of final output to the production of new patented designs that will increase the existing stock of designs A_t to the value that will be available next period, A_{t+1}. If we let C_t denote final consumption goods, final output is divided as follows:

$$\begin{aligned} Y_t &= C_t + K_{t+1} + Z_t \\ &= C_t + \int_0^{A_{t+1}} x_{jt+1} dj + Z_t \end{aligned}$$

The intermediate inputs are like capital that fully depreciates after one period of use, an assumption that is made more palatable by our later calibrated choice of a period that is 10 years long.

The key equation for the dynamics of the model describes the conversion of foregone output or R&D expenditures Z_t into new patents. In period t, each of a large number N of intermediate goods firms indexed by f can use final goods to discover new types of intermediate goods that can then be produced for use in $t+1$. Let M_{t+1} denote the aggregate measure of new goods discovered in period t, and let M_{ft+1} be the measure of these new goods produced at firm f. Here, the letter M is a mnemonic for "monopoly" because goods patented in period t will be subject to monopoly pricing in period $t+1$. Because our patents, like our capital, last for only one period, only the new designs produced in period t will be subject to monopoly pricing in period $t+1$. These assumptions imply that our model period of effective monopoly protection, 10 years, is somewhat shorter than the full length of statutory patent protection in the United States, a notion consistent with a range of empirical papers including Budish et al. (2015).

To allow for the problem that firms face in coordinating search and innovation in larger teams, we allow for a form of diminishing marginal productivity for the inputs to innovation in any given period. Let Z_{ft} denote the resources devoted to R&D or innovation at firm f at time t. We assume that the output of new designs will also depend on the availability of all the ideas represented by the entire stock of existing innovations, A_t. Hence we can write the number of new designs at firm f as:

$$M_{ft+1} = (Z_{ft})^{\rho} A_t^{1-\rho}, \tag{1}$$

where $0 < \rho < 1$.

The exponent on A_t is crucial to the long-term dynamics of the model. The choice here, $1-\rho$, makes it possible for an economy with a fixed quantity of human capital H to grow at a constant rate that will depend on other parameters in the model. As an alternative, we could follow the suggestion in Jones (1995a) and use a smaller value for this exponent, in which case we could generate steady-state growth by allowing for growth in the quantity of H. The two types of model offer different very long-run (100+ year) predictions about the effect that the trade shock on growth, but are similar for the first $\approx$ 100 years, which because of discounting is effectively all that matters for our results. We formally detail and calibrate an extension of our model with semi-endogenous growth and show the results are very similar (see Appendix D).

Another way to characterize the production process for new designs is to convert the innovation production function in equation (1) to a cost function that exhibits increasing marginal costs of innovation in period t,

$$Z_{ft} = \nu M_{ft+1}^{\gamma} A_t^{1-\gamma}, \tag{2}$$

where $\gamma = \frac{1}{\rho} > 1$.

Finally, we note that the parameter ν is a constant which we have introduced to the innovation cost function and will adjust so that different choices of the number of intermediate goods firms N and the innovation cost function curvature γ generate the same balanced growth rate.

Given the innovation cost function for a single intermediate goods firm f, we have that the aggregate R&D expenditure is immediately given by $Z_t = \sum_{f=1}^{N} Z_{ft}$. In most cases, symmetry will allow for substantial simplification of this expression.

3.2 Preferences

A representative household in this economy consumes the final good in the amount C_t each period, inelastically supplies labor input H, and has preferences over consumption streams given by

$$\sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\sigma}}{1-\sigma}.$$

The representative household receives labor income, owns all the firms, and trades a one-period bond with zero net supply. As usual, if consumption grows at a constant rate $g = \frac{C_{t+1}-C_t}{C_t}$, and if r denotes the one-period interest rate on loans of consumption goods, these preferences imply the result

$$1 + r = \frac{1}{\beta}(1+g)^{\sigma}. \tag{3}$$

Because the price of consumption goods is always one unit of the numeraire good, r is also the one-period interest rate on loans denominated in the numeraire.

3.3 Equilibrium

To characterize the equilibrium in this closed economy, we can assume that final goods are produced by a single competitive constant returns to scale firm which demands as inputs intermediate goods and human capital. We also assume that the labor market is competitive.

Each of the intermediate inputs are provided by one of the N intermediate goods firms. These firms design new goods and produce the intermediate inputs that the new designs make possible. After the one-period patent expires, it is convenient and harmless to assume that the firm f that developed a good will continue to produce it. Hence, at any date t, the range of goods $[0, A_t]$ can be divided up in to N disjoint subsets of goods produced by each firm f. Finally, we assume that there is a set of potential entrants in each variety who act as a competitive fringe with access to the same technology for final goods production. This competitive fringe forces the intermediate goods firms which produce off-patent goods to price them at marginal cost via Bertrand competition.

The equilibrium in this model takes a familiar form, with perfect competition in markets for off-patent goods, and monopolistic competition with a zero marginal profit condition for firms that develop new designs that will be protected by patents. The full definition of the equilibrium for this model is given in Appendix A.

The fundamental equation for the dynamics of the model balances the cost of developing a new patented design against the profit that can be earned from the temporary ex-post monopoly that it confers. This profit can be calculated as follows. In period $t+1$, the inverse demand for any input will be the derivative of the aggregate production function, which implies the inverse demand curve

$$p = (1-\alpha)H^{\alpha}x^{-\alpha}.$$

The usual markup rule for a constant elasticity demand curve implies that the monopoly price p_M will be marked up by a factor $1/(1-\alpha)$ above its marginal cost. One unit of output today can be converted into one unit of the intermediate that is available for sale tomorrow, so the marginal cost in units of output tomorrow is $(1+r)$. The monopoly price tomorrow can be written as

$$p_M = \frac{1+r}{1-\alpha}.$$

Together, these two equations imply monopoly output

$$x_M = H\left(\frac{(1-\alpha)^2}{1+r}\right)^{1/\alpha}. \tag{4}$$

Because profit takes the form

$$\pi = \frac{p_M x_M}{1+r} - x_M,$$

this yields

$$\pi = \Omega\,(1+r)^{-\frac{1}{\alpha}}\,H,$$

where $\Omega = \alpha(1-\alpha)^{\frac{2-\alpha}{\alpha}}$ is a useful constant.

One easy way to see why profit increases linearly in H is to note that the price the monopolist sets is a fixed markup over marginal cost. This means that profit increases linearly with the quantity the monopolist sells. As in any constant returns to scale production function, at constant prices an increase in the use of one input such as H will lead to an increase by the same factor in the quantity demanded of all complementary intermediate inputs x_j.

The zero marginal profit condition for developing new goods implies that this expression for π must be equal to the marginal cost of producing the last innovation at each firm. To express this cost, it helps to define a "pseudo-growth rate"[6] for an individual firm, $g^f_{t+1} = \frac{M_{ft+1}}{A_t}$. We denote the economy-wide growth rate of varieties as $g_{t+1} = \frac{M_{t+1}}{A_t}$ and note that $g_{t+1} = \sum_{f=1}^{N} g^f_{t+1}$. Differentiation of the cost function for innovation yields

$$\frac{\partial Z_{ft+1}}{\partial M_{ft+1}} = \nu\gamma\left(g^f_{t+1}\right)^{\gamma-1} \tag{5}$$

[6]This is a pseudo-growth rate because we have divided by the economy-wide stock of patents rather than the firm's own stock of patents. All other growth rates are true growth rates.

On a balanced growth path, g_{t+1} will be equal to a constant g, which will also be equal to the rate of growth of output and of consumption. By symmetry among the N firms, we also have that $g^f_{t+1} = \frac{1}{N}g$. As a result, the cost of a new design reduces to

$$\begin{aligned}\frac{\partial Z_{ft+1}}{\partial M_{ft+1}} &= \nu\gamma\left(\frac{1}{N}g\right)^{\eta(\gamma-1)} \\ &= \nu\gamma N^{(1-\gamma)} g^{\gamma-1}\end{aligned}$$

If we define ν so that

$$\nu\gamma N^{(1-\gamma)} = 1$$

the cost of a new patent reduces to $g^{\gamma-1}$. Equating this marginal cost with the marginal benefit (*ex post* profit) yields:

$$g^{\gamma-1} = \Omega\,(1+r)^{-\frac{1}{\alpha}}\,H. \tag{6}$$

Finally, using the fact that in a balanced growth equilibrium, consumption, patents, and total output will all grow at the same rate g, we can substitute in the expression for the interest rate equation (3) into equation (6) to generate the basic equation relating g and H:

Proposition 1. *Closed-Economy Balanced Growth Path*

The closed economy has a unique balanced growth path with a common constant growth rate g for varieties, output, and consumption, that satisfies the innovation optimality condition

$$g^{\gamma-1} = \Omega\beta^{\frac{1}{\alpha}}(1+g)^{-\frac{\sigma}{\alpha}}H.$$

Proof in Appendix A.

In the closed economy, this proposition says that the marginal cost of a patent must be equal to the appropriately discounted *ex post* profit that it will generate, and that this profit is proportional to the stock of human capital, H. When we extend this to the open economy setting, the same kind of expression in which g is an increasing function of H will still hold except that H will be replaced by an expression that depends on both H in the North, H^* in the South, and the extent of restrictions that limit trade between the two regions.

3.4 Open Economy

Suppose next that there are two regions or countries, North and South. We treat North as the home country so variables associated with the South are indicated with an asterisk. There are identical representative households in the North and South. The final goods technologies of the two regions are identical, but only Northern intermediate goods firms have access to the innovation technology that produces new patents or designs. A firm in the South can subsequently produce any intermediate good as soon as it is off patent.

We show in an extension of the model in Appendix F that allowing for an empirically calibrated level of Southern innovation yields qualitatively similar results. However, no Southern innovation, our baseline assumption, is actually a realistic approximation to the data if we identify the North with OECD nations empirically. As plotted in Appendix Figure B1, patents granted in the US are overwhelmingly from OECD nations. Although non-OECD innovation as measured by patenting is increasing rapidly, the increase is from an extremely low base. For example, China in particular accounts for an average of 1.2% of US patents during 1994-2014.

To allow for a continuum of possible levels of trade liberalization, we assume that the government in the North imposes a trade restriction which allows only a proportion ϕ of off-patent intermediate goods varieties produced in the South to be imported into the North. If we make the simplifying assumption that the goods with the lowest index values are the ones that are allowed to trade, then Figure 2 describes the goods that are used in production in the North and the South. The goods with the lowest index values are called I goods to signal that they are imported into the North. In terms of production in period t, the range of the I goods is from 0 to ϕA_{t-1}. These goods are produced in the South for use in the South and for import into the North. Next come the R (for restricted) goods. These are produced in the North for use in the North and produced in the South for use in the South. Finally, we have the M (for monopoly) goods, which are produced in the North and used in production in both the North and the South. Hence, M_t represents the new goods developed in period $t-1$ for sale in period t; R_t represents the trade-restricted but off-patent goods available for use in production in period t; I_t represents the off-patent goods that can be imported into the North for use in period t. In a small abuse of the notation, we will use the symbols I, R, and M to denote both the set of goods and its measure.

In this two economy model, we can consider a unit of final output, or equivalently the bundle of inputs that produces it, in both the South and the North. We will use output in the North as the numeraire and define the Southern terms of trade q_t as the price in units of final output in the North of one unit of final output produced in the South. We impose trade balance in each period so there is no borrowing between North and South. Along any balanced growth path, the interest rates in the North and South will be the same, but the restriction on borrowing is binding during the short transition to the new balanced growth rate that follows a policy change. The terms of trade q adjust to achieve trade balance in each period, which requires that the value of imports into the North, $q_t p_{It} I_t x_I$, is equal to the value of the goods that the North sells to the South, $p_M M_t x_M^*$.

As in the usual product-cycle model, e.g. Krugman (1979), we are interested only in the case in which the South has a cost advantage in producing goods that it can export, due to its lower wages. On the balanced growth path, this is equivalent to having $q_t < 1$. In our analysis, we restrict attention to the case of values of the trade policy parameter ϕ that are low enough to ensure that this restriction holds.

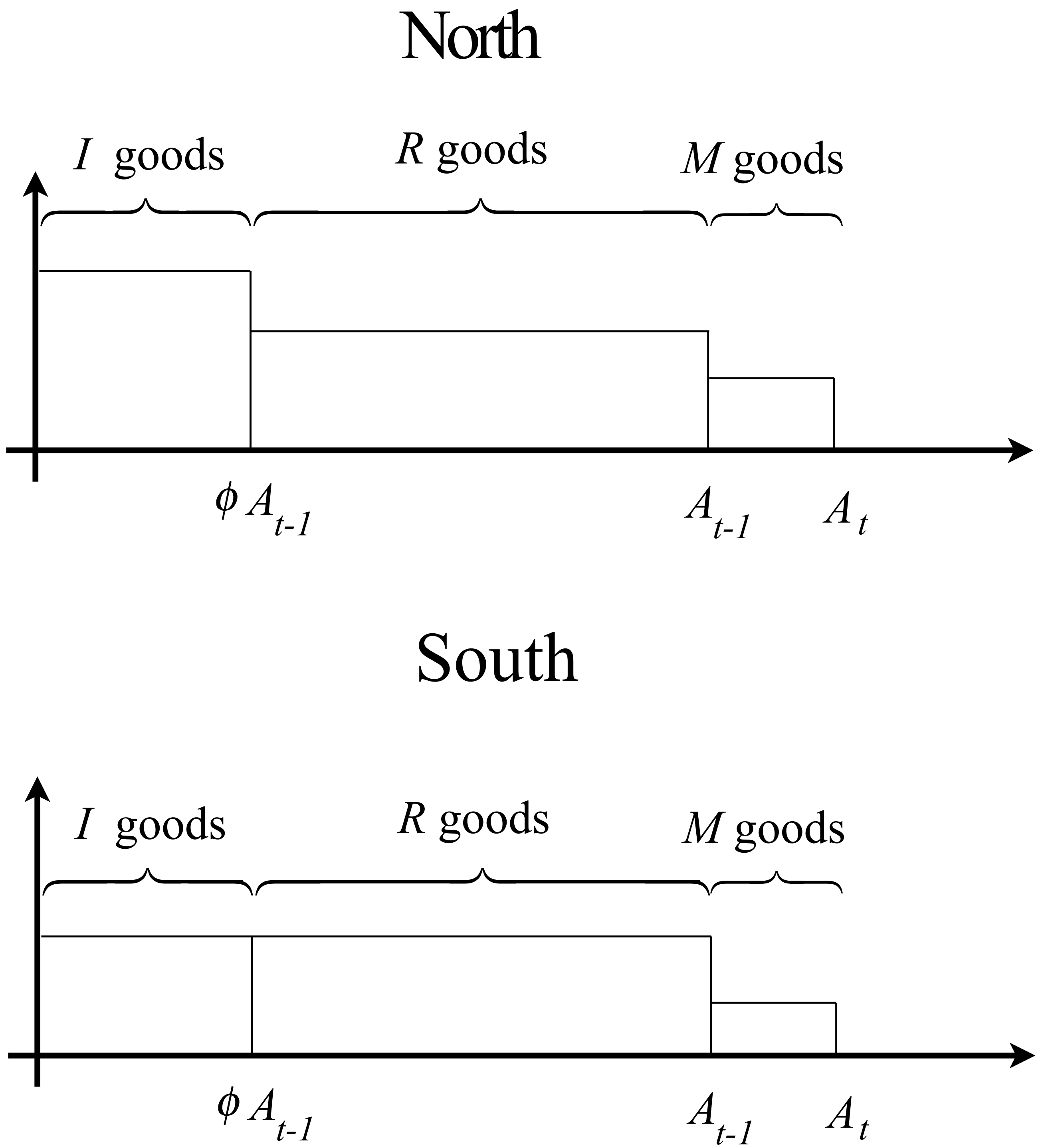

Figure 2: A Product Cycle in the Model

Note: The figure plots the product cycle for intermediate goods in the open-economy model. In the open-economy equilibrium defined and analyzed in the paper, goods in each period will display the above decomposition, into newly innovated M goods produced solely in the North, perfectly competitive but non-traded R goods produced in the North and the South, and perfectly competitive, traded I goods produced solely in the South. The vertical axis plots a stylized version of the equilibrium intensive margin for each class of good.

It is important for the operation of the model that in this case, trade balance does not lead to factor price equalization. Identical workers in the North and the South earn wages that when converted at the terms of trade q are higher in the North and lower in the South. Restricted intermediate inputs that are produced and used only in the South are less expensive there than the same goods produced and used in the North. However, because consumption goods in the South are also less expensive, the difference in the wages is much smaller after a PPP correction.

To describe the equilibrium for the open economy, it helps to define a second (irrelevant) constant $\Psi = (1-\alpha)^{\frac{\alpha-1}{2-\alpha}}$ that is analogous to the constant $\Omega = \alpha(1-\alpha)^{\frac{2-\alpha}{\alpha}}$ for the closed economy. For any given value of the trade parameter ϕ, a straightforward extension of the analysis for the closed economy yields a two-equation characterization of the balanced growth rate and the associated terms of trade:

Proposition 2. *Open-Economy Balanced Growth Path*

For low enough values of the trade parameter ϕ, the world economy follows a balanced growth path with a common, constant growth rate of varieties, worldwide output, and consumption in each region. The growth rate $g(\phi)$ and the terms of trade $q(\phi)$ are determined by the zero marginal profit condition for innovation

$$g(\phi)^{\gamma-1} = \Omega\beta^{\frac{1}{\alpha}}(1+g(\phi))^{-\frac{\sigma}{\alpha}}\left(H + q(\phi)^{\frac{1}{\alpha}}H^*\right) \tag{7}$$

and the balanced trade condition

$$q(\phi) = \left(\frac{\phi H}{g(\phi)H^*}\right)^{\frac{\alpha}{2-\alpha}}\Psi \tag{8}$$

with $q(\phi) < 1$.

Proof in Appendix A.

After substitution of equation (8) into equation (7), the growth rate $g(\phi)$ can be seen to be determined by the intersection of a downward sloping innovation marginal profit curve with an upward sloping innovation marginal cost curve. For clarity, see Figure 3 which plots a stylized version of the equilibrium innovation optimality condition and the result in Proposition 2. The marginal profit of innovation is strictly increasing in the trade openness parameter ϕ, so the open economy balanced growth rate is strictly increasing in ϕ. This implies, after manipulating Equation (7), that the terms of trade $q(\phi)$ is also strictly increasing in ϕ.

Proposition 2 is an important result as it establishes that trade liberalization will increase growth rates as it increases the incentive to invest in innovation. Essentially this is because the effective size of the market has expanded and this increases the profitability for new goods. R&D investments increase until at the margin ex-ante expected profits are again zero, but this will be at a higher growth rate.

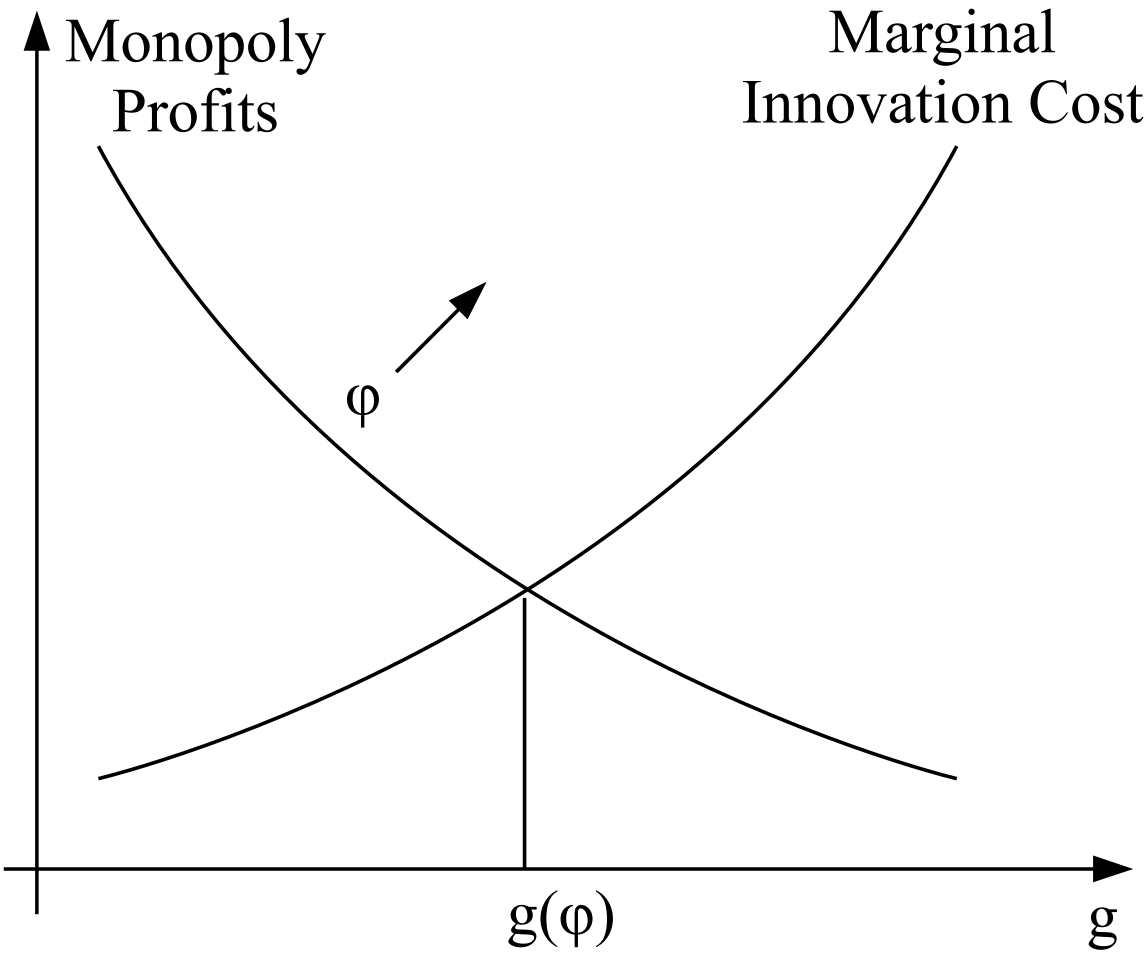

Figure 3: Steady-State Growth Path Equilibrium

Note: The figure plots the equilibrium innovation optimality condition for Northern intermediate goods firms in the steady-state growth path of the open-economy model. The innovation optimality condition pins down steady-state growth path growth rates in this framework, and as implied by Proposition 2 increases in the returns to innovation induced by increases in ϕ lead to strictly higher long-run growth rates.

Revealingly, the innovation optimality condition (7) is quite similar to the one in the closed-economy version (Proposition 1). Except in place of H, the term $H + q(\phi)^{\frac{1}{\alpha}} H^*$ now determines the extent of the demand for any input and the profit that it will generate. The reason is that all innovation takes place in the North. The worldwide demand for newly invented goods in the North depends on demand in the North, which is proportional to H, and on demand from the South, which is proportional to H^* but includes a downward adjustment induced by the terms of trade.

A trade liberalization caused by an increase in ϕ leads to an increased flow of imported I goods from North to South. The elasticity of demand for all inputs is $\frac{1}{\alpha} > 1$, so revenue declines when prices increase. This means that to balance trade in response to the increase in imports into the North, the prices of the goods that the North imports must go up and the prices that it receives for goods that it sells to the South must go down. Both imply an increase in q. Lower prices in the South for the exported monopoly goods increase the returns to innovation in the North. In equilibrium the rate of innovation, and hence the rate of growth, must increase. This increases the marginal cost of innovation and re-establishes the zero profit condition at the margin.

3.5 Trade Shocks

The open economy analysis above characterized the constant perfect foresight growth rate associated with a constant value of the parameter ϕ. Next, we start from a balanced growth path trade with trade policy ϕ and consider the effects of an unanticipated and permanent trade shock to a more liberal trade regime with $\phi' > \phi$. To carry this exercise out, we must be more explicit about the timing of decisions relative to the announcement of the change in ϕ.

First, it helps to think more concretely about the relationship between the trade restriction ϕ and the measure of varieties produced at each intermediate goods firm in the North. When ϕ is constant, a constant fraction of the off-patent goods that each intermediate input firm in the North had previously produced under trade protection are exposed to import competition in each period. In the aggregate, the total stock of goods that are available as imports in period t is equal to ϕ times the off-patent goods in period t, or ϕA_{t-1}. For simplicity, we assume that this process of exposure is evenly distributed across all intermediate input producing firms. Firms can take account of the predictable shrinkage in the goods that they can produce when they make their decisions about how much of each type of input to acquire.

In contrast, if a government mandates for period 1 an unanticipated increase in ϕ to ϕ', there will be a jump in the number of goods that are subject to import competition. At the aggregate level, the measure of goods which unexpectedly become unprofitable for Northern firms is $A_0(\phi' - \phi)$.

To match the micro data, which indicates that some firms are exposed to larger trade shocks than others, we want to allow for the possibility that this range of goods $A_0(\phi' - \phi)$ is not equally distributed among all firms. To do this, we split the set of intermediate input producing firms in the North into two groups of equal size. We refer to these as the "Shocked" and "No Shock" firms. We assume that all the goods that are unexpectedly exposed to competition from imports are goods that were previously manufactured by the Shocked firms.

With these preliminaries in mind, Figure 4 presents the timeline of events within the period of a trade shock. The trade shock is announced at period 0 and becomes effective in period 1. We present two alternative sets of assumptions. In the first case, the "Fully Mobile" economy, firms can change their input decisions to accommodate the lost R goods production because their input demand choices are made after the new trade policy ϕ' is announced by Northern policymakers. By contrast, in the "Trapped Factors" case, we assume that firms make their input choices before the announcement of the new trade policy. Furthermore, we assume that all inputs, i.e. a bundle of both human capital and intermediates embodied in final output, are trapped within firms in the period of a trade shock. Inputs are trapped because of adjustment costs preventing re-assignment either across firms or into released consumption. The timing of events across the two alternative assumptions is otherwise identical. Furthermore, in all periods before and after the trade shock in period 0, realized policy is identical to anticipated policy and no adjustment frictions bind in either economy.[7]

We pause here to discuss the plausibility of our Trapped Factors assumption in more detail. In essence, we assume that adjustment costs trapping inputs within firms are entirely prohibitive or infinite in magnitude. While convenient analytically and for exposition, because we do not have to make strong assumptions about the exact form of the adjustment cost function, this is *not* required for our numerical results. As we will highlight in the next section, the shadow value of inputs falls by around 31% for the most heavily affected Shocked firms in our Trapped Factors economy in the face of a calibrated trade shock. Therefore, alternative finite levels of input specificity or other adjustment costs in a generalized version of the model would need only to be able to prevent adjustment in the face of moderate shifts in the internal value of inputs. Structural studies of input adjustment costs routinely yield empirical estimates much higher than this, e.g. around 35% irreversibility in the case of tangible capital inputs in Bloom (2009), so we find our adjustment cost assumption to be entirely plausible.

In order to calculate the full general equilibrium effects of a trade shock, we must take into account not only impact effects on input demands but also any induced changes in interest rates and the terms of trade. The full equilibrium definitions for the closed economy, the open economy, and the trade shock economies can be found in Appendix A.

Before moving to the numerical experiment, we also note that the description above is based upon our assumption that competition within the market for each off-patent variety takes place

[7] Note also that in both the Fully Mobile and Trapped Factors economies, a sudden increase in imports from the South requires the immediate takeover of these production lines by Southern intermediate goods firms. We assume that in both cases, Southern intermediate firms anticipate the trade shock to allow for the sudden export jump.

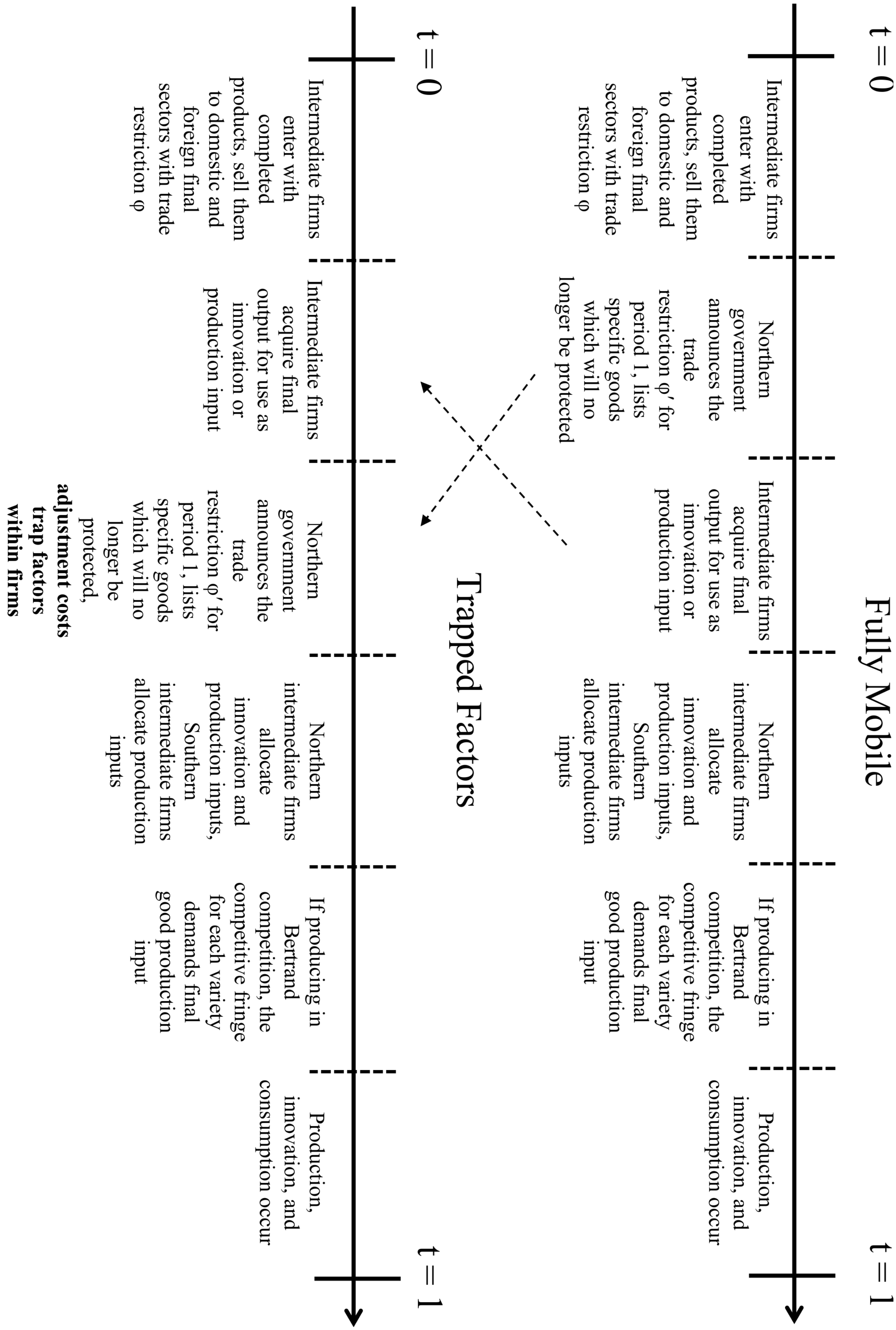

Figure 4: Timing of a Trade Shock

Note: This figure lays out the timing of trade shock announcement in the model. The upper timeline describes the assumptions of the Fully Mobile economy, and the bottom timeline describes the assumptions of the Trapped Factors model.

between only the intermediate goods firm which innovated that variety and a competitive fringe for that variety. In particular, another innovating firm cannot compete within the off-patent market of another intermediate goods firm, implying that any firms affected by a trade shock need simply to determine their input allocation between innovation of new varieties and production of their own remaining off-patent varieties. Given that our trapped factors timing assumption can be equivalently reframed as an assumption of input specificity, such a partition is natural.[8]

4 Numerical Analysis: OECD Trade Liberalization with Non-OECD Countries

We can now calibrate and perform a suggestive numerical exercise with the model, considering the impact of a trade shock over a full transition path. Appendices B and C give more details on the calibration and solution.

First, as mentioned above, we assume a model period of 10 years. Then, we calibrate the model economy to match long-run growth rates, and movements in trade flows between the OECD and non-OECD countries from 1994-2014, spanning the decades around Chinese WTO accession in 2001. As plotted in Figure 1, imports from non-OECD countries into the OECD almost doubled as a proportion of GDP over this period but appear to have stabilized. China in particular accounts for almost half of the increase in low-wage imports. To match this pattern from the data, the model experiment we consider is an unanticipated, permanent trade shock moving from the steady-state growth path from trade policy ϕ to a new liberalized policy ϕ', as detailed in the theory section above.

4.1 Calibration

We started by specifying the basic parameters about which we have some prior information. Following Jones (1995b) and King and Rebelo (1999) we consider the case of log utility with $\sigma = 1$ and a labor share in production of $\alpha = \frac{2}{3}$. Steady-state growth path real interest rates of approximately 4% require $\beta = (0.98)^{10}$. We also estimated the ratio $\frac{H^*}{H} \approx 3$ from international schooling data on educational attainment in the OECD and non-OECD countries in the year 2000. Therefore, we identify the OECD nations in our sample with the North and non-OECD nations with the South. We fix the parameter ρ to the baseline value of $\rho = 0.5$ based on the empirical results in Bloom et al. (2013b) or Blundell et al. (2002). Appendix B contains more information

[8] It is easy to analyze what would occur under the alternative assumption that intermediate goods firms could substitute towards production of another intermediate goods firm's off-patent varieties. In this case, Bertrand competition would dictate that the firm with the lower shadow value would take over a market. In equilibrium, the only possible outcome is equalization of shadow values through Shocked firms takeover of varieties previously produced by No Shock firms. Such an assumption would then eliminate heterogeneity in the behavior of Shocked and No Shock firms, directly contradicting our empirical evidence in Section 2 which suggests that innovation systematically varies with low-cost import competition in the cross-section.

on the calculation of H/H^*, and a later section checks robustness to different values of most of the parameters above.

Table 2: Long-Run Impact of Liberalization

%	Pre-Shock	Post-Shock
Imports to GDP	3.5	8.4
Growth Rate	2.0	2.6
Southern Terms of Trade	0.5	0.7

Note: The table above displays pre- and post-shock values of the main quantities within the model. The values reflect the long run or the steady-state growth path in the baseline experiment in the model. All quantities are in annualized percentages except for the Southern terms of trade which is equivalent to the model relative price q.

We must also choose the final three parameters H, ϕ, and ϕ' which jointly govern the model's long-run steady-state growth rates and imports to output ratios. We compute the ratio of non-OECD imports to OECD GDP in 1994 (3.5%) and 2014 (8.4%), requiring that the model reproduce these import ratios in the pre- and post-shock steady-state growth paths, respectively. In other words, we require that the model reproduce the endpoints of the non-OECD imports series plotted in Figure 1. These import ratios are heavily influenced by our choice of ϕ and ϕ', leaving us still to determine the model's scale through the choice of H to match growth rates from the data. We note that the model's concept of growth is most closely aligned with frontier per-capita GDP growth. We therefore prefer to calibrate long-run frontier growth to the per-capita GDP growth of the United States rather than the entire OECD. We choose a wide sample window of 1960-2010, yielding a calibration of H to match a pre-shock average annual growth rate of 2.0%.

For each quantitative experiment we perform below, including the presentation of long-run results, transition paths, and robustness exercises, we follow the strategy described above to choose the size of the trade policy and the scale parameters H, ϕ, and ϕ' to ensure that the model reproduces the change in import ratios and growth rates in each case. This ongoing implementation of the calibration strategy ensures that we compare trade shocks of comparable magnitude for trade flows at all times, improving comparability of our results across different cases. Since the Fully Mobile and Trapped Factors version of the model for the same parameters have identical long-term implications for the targeted moments, the resizing of the trade shock only effects experiments in which the parameters of the model are changed.

4.2 The Long-Term Impact of a Trade Shock

We summarize the long-term impacts of trade liberalization in our baseline model in Table 2. To reproduce the changes in the OECD imports to GDP ratio observed in the data for the baseline parameterization of the model requires an exogenous increase in trade policy ϕ from 8.4% to 26.0%, and this exogenous change produces, through the effective market size effect discussed in

Table 3: Trade Shocks, Short-Term Growth, and Welfare Gains		
%	Short-Term Growth, $t = 1$	Northern Welfare Gains, Full Transition
Fully Mobile	2.6	22.8
Trapped Factors	3.0	25.6

Note: The first column of the table above presents the variety growth rate in the first period of a trade shock, $t = 1$, and the second column presents the consumption-equivalent welfare gain of the Northern consumer from trade liberalization, taking the full transition path into account. Each row represents one of two alternative economies. They are the Fully Mobile and Trapped Factors economies, with liberalization experiments and long-run effects of trade shocks identical to those laid out in Table 2.

Section 3, a movement in the long-term growth rate from its pre-shock calibrated value of 2.0% to a new value of 2.6%.

4.3 Transition Dynamics in the Fully Mobile Economy

Next we consider the transition dynamics of the fully mobile economy, starting from the steady-state growth path associated with trade policy ϕ and allowing an unanticipated and permanent trade policy shock $\phi \to \phi'$ that is announced in period 0 to become effective in period 1.

In Figure 5, we plot the aggregate transition dynamics of the Fully Mobile economy for aggregate variety growth, the terms of trade, and output growth in the North and South. Although it remains unplotted in this figure, consumption growth follows the pattern of output growth almost identically.

The full transition to the new steady-state growth path is complete after approximately 6 periods (60 years). Given the trade liberalization shock, the Southern terms of trade increases rapidly to maintain balanced trade, leading to an associated increase in the returns to innovation and hence the aggregate variety growth rate. Consumption smoothing dictates a slower, smooth transition of output growth rates to their long-run values. The slight overshooting of variety growth in period 1 is due to the fact that Northern interest rates are initially lower than their new long-run levels, decreasing the marginal cost of innovation and raising the return to innovation for Northern firms in the short run.

We can also compute the long-run welfare gains from trade in the fully mobile environment, taking the transition path into account, and we report these in Table 3. The North gains by a consumption equivalent of 22.8%, while the South gains by a consumption equivalent of 21.3%. In other words, we would have to increase the consumption of the Northern household *without* trade liberalization by 22.8% in every period to make it as well off is it would be in the equilibrium with the trade liberalization. The details of the welfare calculations are available in Appendix C. Also, note that the slight difference in welfare gains across economies is due to the fact that the Northern consumer disproportionately benefits from the lower price of Southern goods in the North, an advantage absent for the Southern consumer. Overall, the higher rate of growth induced by liberalization can be a powerful source of welfare improvement from trade.

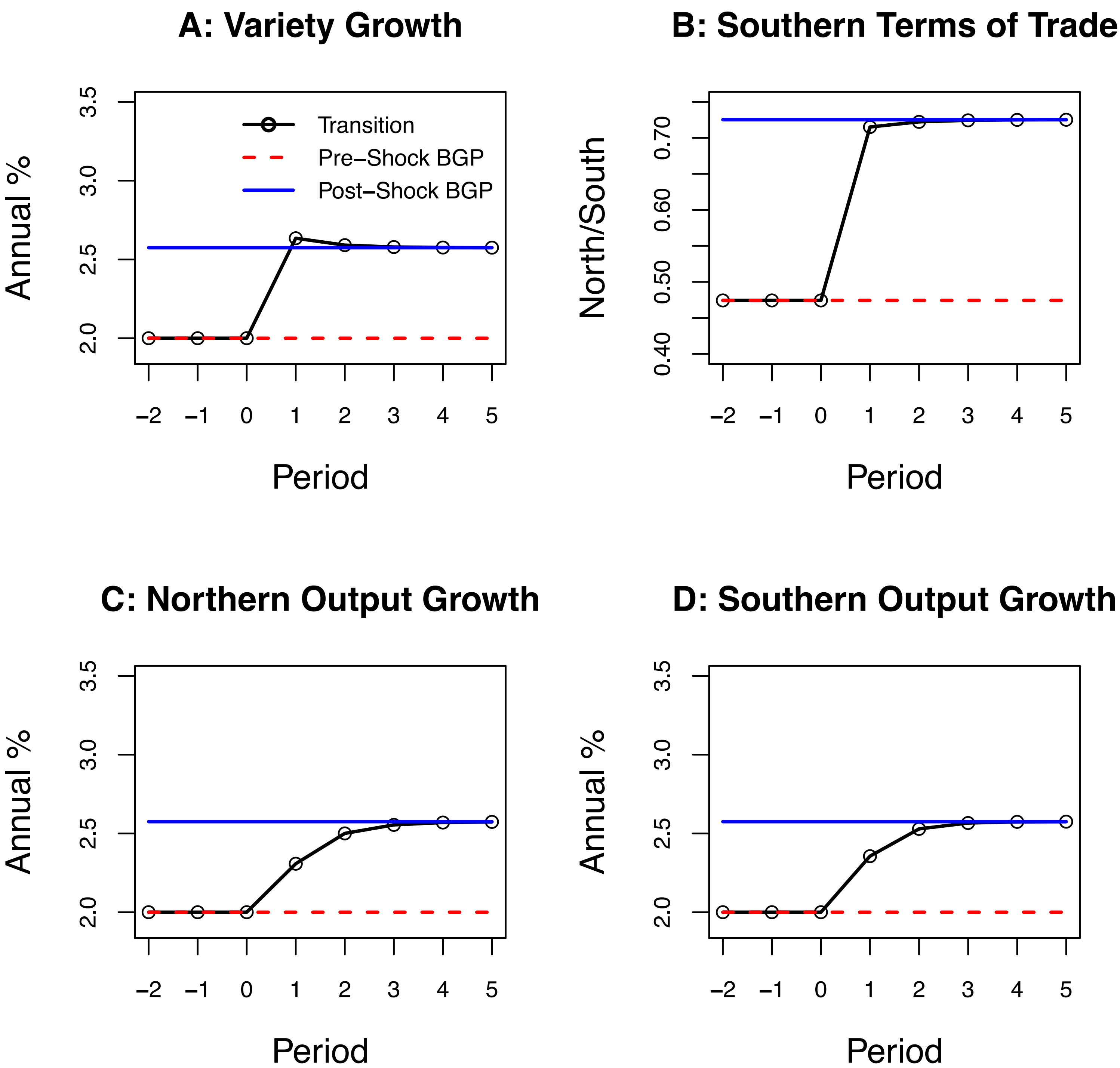

Figure 5: Liberalization Boosts Growth in the Fully Mobile Model

Note: The figure displays the transition path in response to a permanent, unanticipated trade liberalization from policy parameter ϕ to $\phi' > \phi$, which is announced in period 0 to become effective in period 1. The plotted transition is computed in the Fully Mobile economy, in which intermediate goods firms may respond to the information about trade liberalization without short-term adjustment costs. The solid black line is the transition path, the upper horizontal solid blue line is the post-shock steady-state growth path, and the lower horizontal dashed red line is the pre-shock steady-state growth path.

4.4 Transition Dynamics in the Trapped Factors Economy

In Figure 6 we plot the path of some selected aggregates over a Trapped Factors transition path. Comparing the Trapped Factors transition with the Fully Mobile transition in Figure 5, we immediately note that the variety growth rate is higher upon impact of the trade shock. Instead of a growth rate of about 2.6% in the shock period as seen in the fully mobile transition, the trapped factors variety growth rate on impact is 3.0%. The increased Northern innovation and flow of M goods from North to South in the shock period slows the appreciation in the Southern terms of trade, and output growth in the North and South both overshoot their long-run levels after the trade shock. The transition path is again complete in approximately 6 periods. Since each model period is a decade, each transition path takes around 60 years, and the impact of short-run adjustment costs manifests itself mostly in the first decade or period after the trade shock. Overall, the path of innovation is clearly significantly higher in the presence of short-run adjustment costs or trapped factors.

Recall that we assume that there are two industries with half of the firms each. One of these industries (Shocked) contains all the shocked firms and bears the brunt of the direct effects of liberalization. The other industry, No Shock, has no liberalized R goods. In Figure 7, we plot three separate patent flows. In the solid black bar on the left labeled Pre-Shock, we present period 0 or pre-shock patent flows for the Shocked and No Shock industries, which are ex-ante identical. These patent flows are arbitrarily normalized to $1,000$ for ease of reference. The blue middle bar with downward-sloping lines and the red right bar with upward-sloping lines, by contrast, plot the patent flows for industry No Shock and for industry Shocked during period 1, the period in which policy liberalization becomes effective. Although both industries increase patenting during the shock period due to terms of trade movements, the Shocked industry patents approximately 36.8% more in the period after the shock.

The differential impact in Figure 7 of trade shocks on innovation across exposure levels with Trapped Factors is entirely absent in the Fully Mobile economy. To understand this result, note that in the Fully Mobile economy both Shocked and No Shock firms engage in innovation and choose patenting in order to set the marginal cost of innovation in equation (5) equal to the discounted marginal benefit of innovation. Since resources can flow freely into and out of all firms under full mobility, and since all firms in this case earn identical discounted profits from innovation in the next period, all firms will choose identical forward-looking patenting levels in period 1. Our model therefore implies that the presence of trapped factors or input adjustment costs is crucial because it leads to higher sensitivity of patent growth to trade liberalization in the cross section. This implied link is consistent with our disaggregated empirical results from Table 1 documenting a larger increase in innovation in those industries and firms more exposed to China. Such sensitivity to import exposure allows us to empirically link innovation to trade shocks, and the rest of our model framework reveals that the aggregate time series - not just disaggregated cross-sectional - link between trade and innovation remains positive.

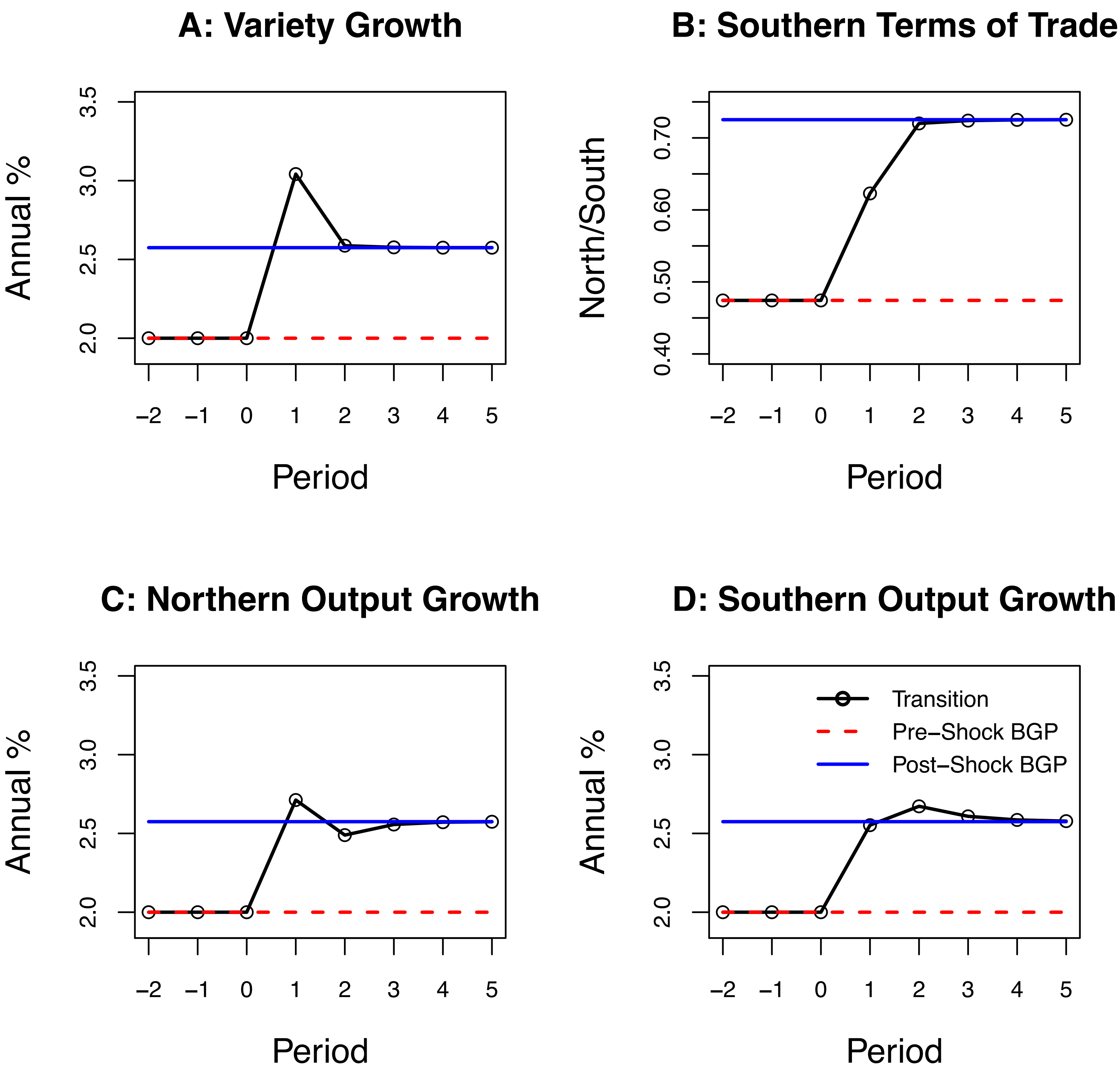

Figure 6: Trapped Factors Increase Short-Run Growth

Note: The figure displays the Trapped Factors transition path in response to a permanent, unanticipated trade liberalization from policy parameter ϕ to $\phi' > \phi$, which is announced in period 0 to become effective in period 1. Since the plotted transition is computed in the Trapped Factors economy, adjustment costs prevent the movement of resources outside of intermediate goods firms within the period of the shock. The solid black line is the transition path, the upper horizontal solid blue line is the post-shock steady-state growth path, and the lower horizontal dashed red line is the pre-shock steady-state growth path.

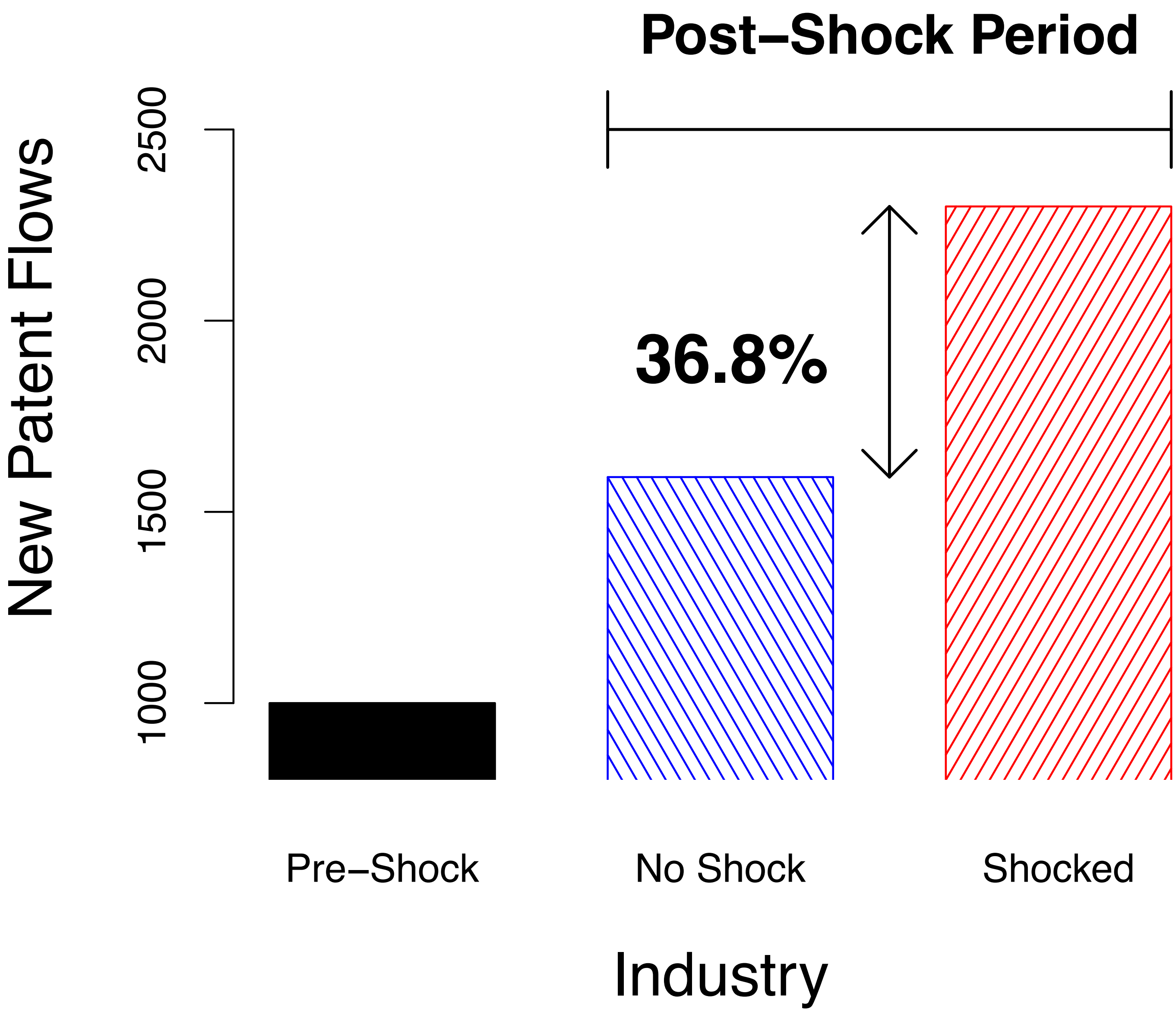

Figure 7: A Shocked Industry Patents More

Note: The solid black bar on the left displays the level of industry patenting in the period before a permanent and unanticipated trade liberalization from policy parameter ϕ to $\phi' > \phi$. Patent flows in the pre-shock period are normalized to equal 1000. The middle blue bar with downward-sloping lines and right red bar with upward-sloping lines represent the response of the No Shock and Shocked industries, respectively, to the trade liberalization in an economy with trapped factors. The Shocked industry loses 25.0% of its previously protected R goods production opportunities when these are converted to imported I goods from the South, and the No Shock industry does not lose any unanticipated R goods to Southern competition.

The stark increase in innovation or patenting at firms in the shocked industry is directly linked to a surplus of resources useful for R&D at those firms, which suddenly lose 25% of their R goods varieties to import competition. In Figure 8 we expand the set of variables included in the Trapped Factors transition path. In the top two panels we can see the shadow value of resources in each industry, which in times without trade shocks is normalized to 100%. Since the lost R goods opportunities imply a surplus of inputs which must be allocated to the unanticipated use of innovation, on the top left panel we see an opportunity cost or resource shadow value decline of 31% in period 1 for firms in the Shocked industry. As noted above, these declines in the shadow value of inputs are moderate compared to existing empirical estimates of adjustment costs within firms, lending plausibility to our underlying trapped factors assumption.

In the upper right panel of Figure 8 we also see a much more moderate decline in opportunity costs by around 11% at firms in the No Shock industry. This is less intuitive and operates entirely through general equilibrium channels. To understand this, we must examine the movements in interest rates also recorded in Figure 8. The sudden increase in variety growth in the Northern economy in the shock period induces an increase in consumption growth rates and hence interest rates. Therefore, even though this does not represent an increases in resources within the No Shock firms, the higher interest rates and hence changed marginal valuations of their Northern owners require a fall in these firms' shadow values to deliver consistency with their value-maximization problem.

Turning again to welfare measures, the total consumption equivalent welfare increases from the trade shock with trapped factors are 25.6% for the North, compared to the 22.8% dynamic gains in the fully mobile case discussed above. To understand this larger welfare gain from trapped factors, note that the externalities in the innovation process through which previous ideas at one firm assist later innovation by all firms are not taken into account in the firm's innovation optimality conditions. Hence, there is "too little" R&D from a social welfare perspective, as is typical in endogenous growth models. The initial increase in variety growth due to the trapped factors mechanism helps to moderate this social inefficiency and leads to a welfare increase in our model.

Compared to the aggregate gains of 22.8% from liberalization in the Fully Mobile case, the Trapped Factors mechanism adds a bit over a tenth or 2.9% to the welfare impacts of liberalization. Clearly, the quantitatively dominant factor for welfare after a trade liberalization is the overall dynamic gains from trade which would exist even in the absence of the Trapped Factors mechanism. While highlighting the potentially large size of these overall gains is one contribution of our paper, Trapped Factors still play a meaningful role for two reasons. First, the growth impacts of the Trapped Factors mechanism are front-loaded and concentrate in the first decade after a liberalization. Such horizons may be particularly relevant for policymakers considering liberalization events. Second, the inclusion of Trapped Factors in the model allows us to match the cross-sectional pattern of patenting which increases with trade exposure, a pattern evident in

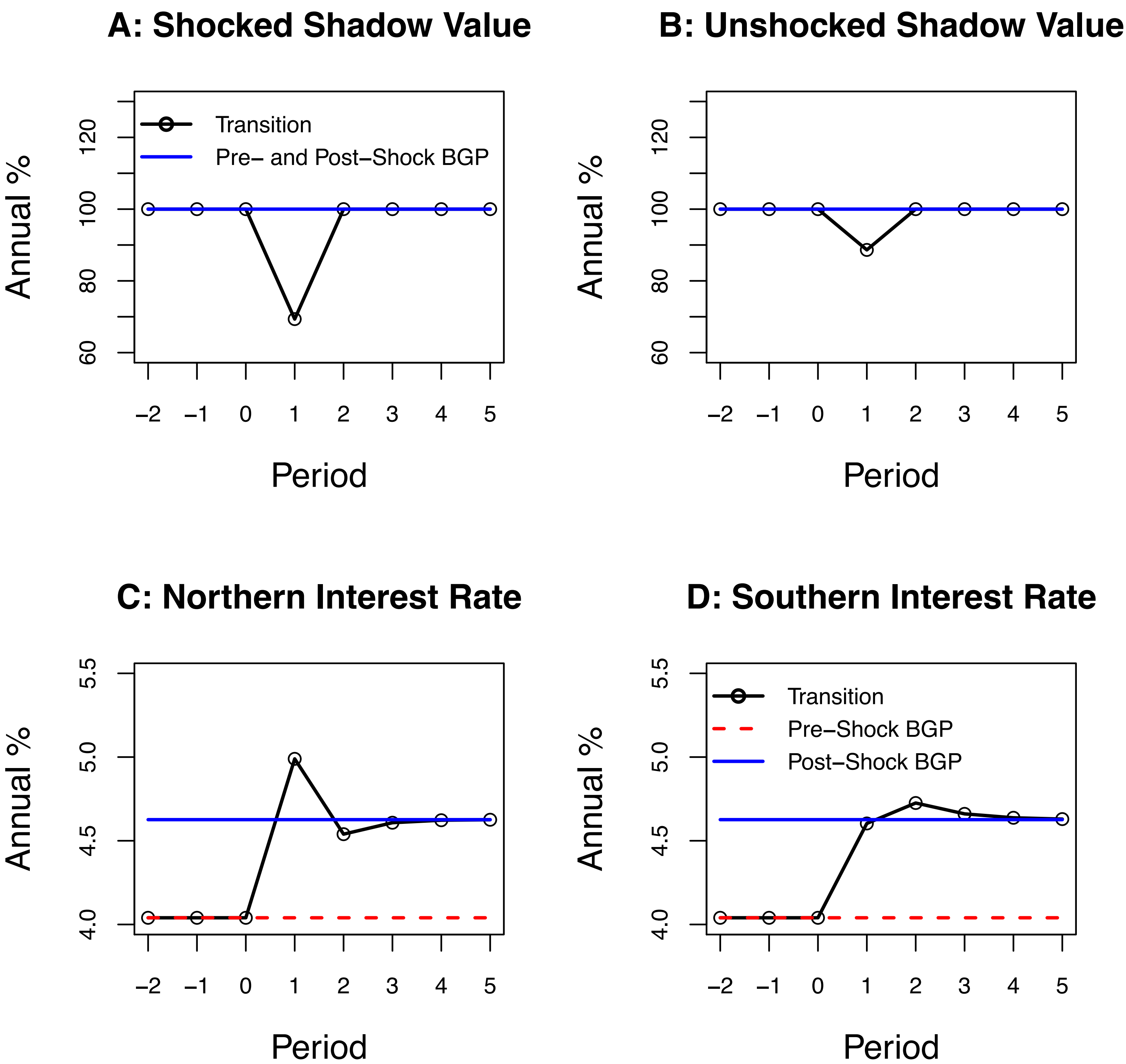

Figure 8: Trapped Factors Interest Rates and Shadow Values

Note: The figure displays the Trapped Factors transition path in response to a permanent, unanticipated trade liberalization from policy parameter ϕ to $\phi' > \phi$, which is announced in period 0 to become effective in period 1. Since the plotted transition is computed in the Trapped Factors economy, adjustment costs prevent the movement of resources outside of intermediate goods firms within the period of the shock. The solid black line is the transition path, the upper horizontal solid blue line is the post-shock steady-state growth path, and the lower horizontal dashed red line is the pre-shock steady-state growth path. For the two shadow value figures, shadow values are normalized to equal 100% in non-shock periods.

Figure 7 in the model and Table 1 in the data but which is absent in the Fully Mobile case with symmetric trade responses across firms. Therefore, the Trapped Factors mechanism serves as a concrete, useful check on the plausibility of our model of growth and trade, regardless of its overall role in the total welfare gains from trade.

4.5 What is the Contribution of China to OECD Growth?

Our model suggests that there was a market size effect and a trapped factors effect from the expansion of low-wage country trade. Given the intense policy interest and recent academic literature in the area, we now consider the incremental effect of the increased trade with China alone. To do this, we scale back the trade shock by assuming that from 1994 to 2014 exports from other countries grew as they did in reality but that exports from China remained constant as a fraction of OECD GDP. With the resulting "No China" counterfactual, maintaining our trapped factors assumption, we can calculate by how much growth and welfare increase in our baseline because of the effect of China alone.

Over the period 1994 – 2014, Chinese exports as a share of OECD GDP increased by 2.5 percentage points from 0.5% to 3.0%. So of the 4.9 percentage point increase in non-OECD import shares, over half was from China. Figure 9 plots the Trapped Factors transition path in the baseline and No China cases. The growth and terms of trade effects of liberalization are dampened considerably.

In the North, the consumption-equivalent welfare gain for the North of the baseline transition path relative to the No China case is approximately 10.2%, and approximately 9.8% in the South. Compared to the baseline gains from trade liberalization considered above of 25.6%, this implies that the Chinese contribution to the gains from liberalization is approximately 40% of the whole. The long-run growth effects of China are similarly substantial, with post-liberalization steady-state growth rates in the No China case of 2.3% rather than the baseline 2.6%, a contribution of approximately 0.3%. We conclude that understanding the OECD and Chinese policies which contributed to the increased trade with China is crucial when quantifying dynamic gains from liberalization over this period.

A caveat to this strategy is that it assumes a counterfactual world in which policy-makers do not make up the gap by relaxing restrictions on non-Chinese low-wage imports. If such a relaxation did take place this would reduce the marginal contribution of China to welfare. In a robustness check in Appendix B, we compute the marginal impact of China with half of all Chinese import growth allowed in as imports from the non-OECD non-Chinese countries. As expected, these results essentially halve the Chinese contribution to innovation and welfare.

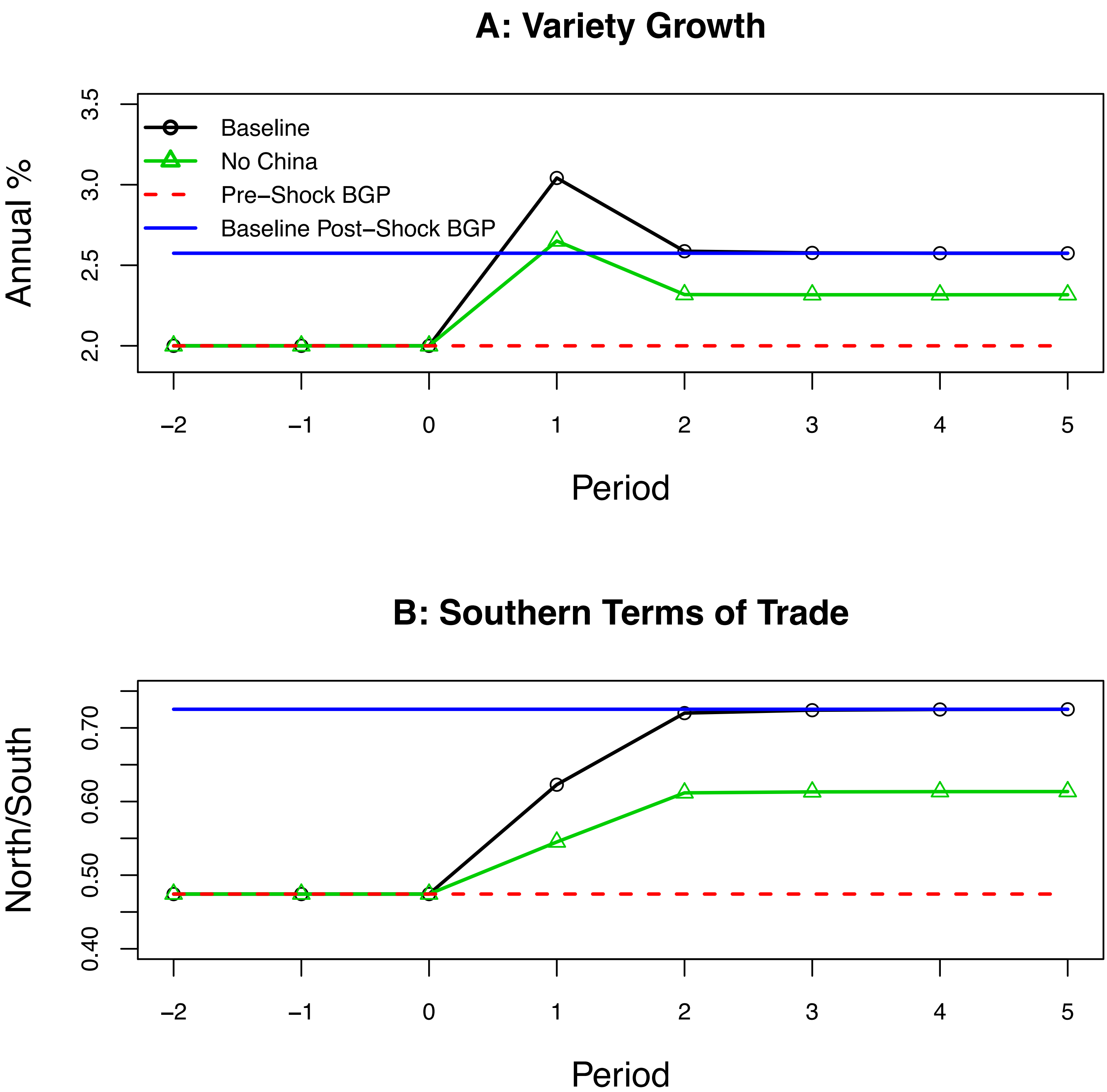

Figure 9: Trade Liberalization without Chinese Import Growth

Note: The figure displays the transition path in response to trade liberalization in two scenarios. The first transition path, in solid black, "Baseline," replicates the Trapped Factors transition path displayed in Figure 6 above. A permanent and unanticipated trade liberalization from ϕ to $\phi' > \phi$ is announced in period 0 to become effective in period 1. The second transition path in green with triangle symbols, "No China," plots the Trapped Factors transition path, starting with the same initial conditions as "Baseline," but instead considering a counterfactual increase of ϕ to a level between ϕ and ϕ' which matches post-liberalization imports to GDP ratios assuming no growth in Chinese imports into the OECD. The upper horizontal solid blue line is the post-shock steady-state growth path, and the lower horizontal dashed red line is the pre-shock steady-state growth path.

4.6 Decomposing Output Growth: Price vs Variety Effects

In our model, trade liberalization impacts the economy due both to static price factors - lower cost R goods in the North - and also due to dynamic variety effects - higher growth in the South and North each period. The effects of the price reductions echo – although are distinct from – the more traditional static models of trade liberalization along the lines of Melitz (2003) or Eaton and Kortum (2002). In this section, we seek to roughly decompose the impact of trade into price vs variety effects. One way to perform this analysis would be to consider a special case of our model with only static trade forces in place. However, in our product-cycle model with growth, trade between the high-cost Northern economy and the low-cost Southern economy takes place when newly innovated M goods are available in each period to be sold by the North to the South in exchange for existing but lower-cost R goods. So we don't nest a purely static model of trade to use for that purpose, and we emphasize that our model is not directly comparable to traditional quantitative static trade models. Instead, we decompose the observed growth in our model into portions due to distinct price and variety channels, with results summarized in Figure 10.

Consider the Northern economy. We start from output in any period $t-1$, which depends both upon the mass of varieties of each category M, R, and I used as well as the price of each good. We compute the output growth which occurs from the static reduction in the price of existing R goods converted into lower-cost I varieties from $t-1$ to t, keeping the total quantity of varieties fixed. This portion of growth - the *Cheaper R to I Goods* effect in Figure 10 - reflects solely the static price effect of trade liberalization alone. Then, we compute the output growth which occurs from the conversion of monopoly protected M goods from period $t-1$ into lower cost off-patent R goods in period t, again holding the total mass of varieties constant. This second portion of growth - the *Cheaper M to R Goods* effect - reflects static price gains based on the alleviation of patent-based markups rather than trade directly, i.e., it would exist in classic endogenous growth frameworks in closed economies. The third and remaining portion of growth to the observed level of output in period t - the *New M Goods* effect in Figure 10 - mainly depends upon the dynamic force of new M goods and an overall increase in the mass of varieties in the economy. For interested readers, Appendix C provides more details and exactly defines each intermediate contribution to output growth.

The top Panel A of Figure 10 reports these contributions to output growth in the North for four periods of interest from left to right: 1) any period on the pre-shock balanced growth path, 2) the impact period 1 of trade liberalization along the Fully Mobile transition path, 3) the impact period 1 of trade liberalization along the Trapped Factors transition path, and 4) any period on the post-shock balanced growth path. The bottom Panel B plots a similar decomposition for Southern output growth. Since all off-patent goods in the R or I categories cost the same from a Southern perspective, the Cheaper R to I goods static price effect is absent for the Southern economy.

Figure 10 reveals that in the steady-state balanced growth paths the purely static price effects

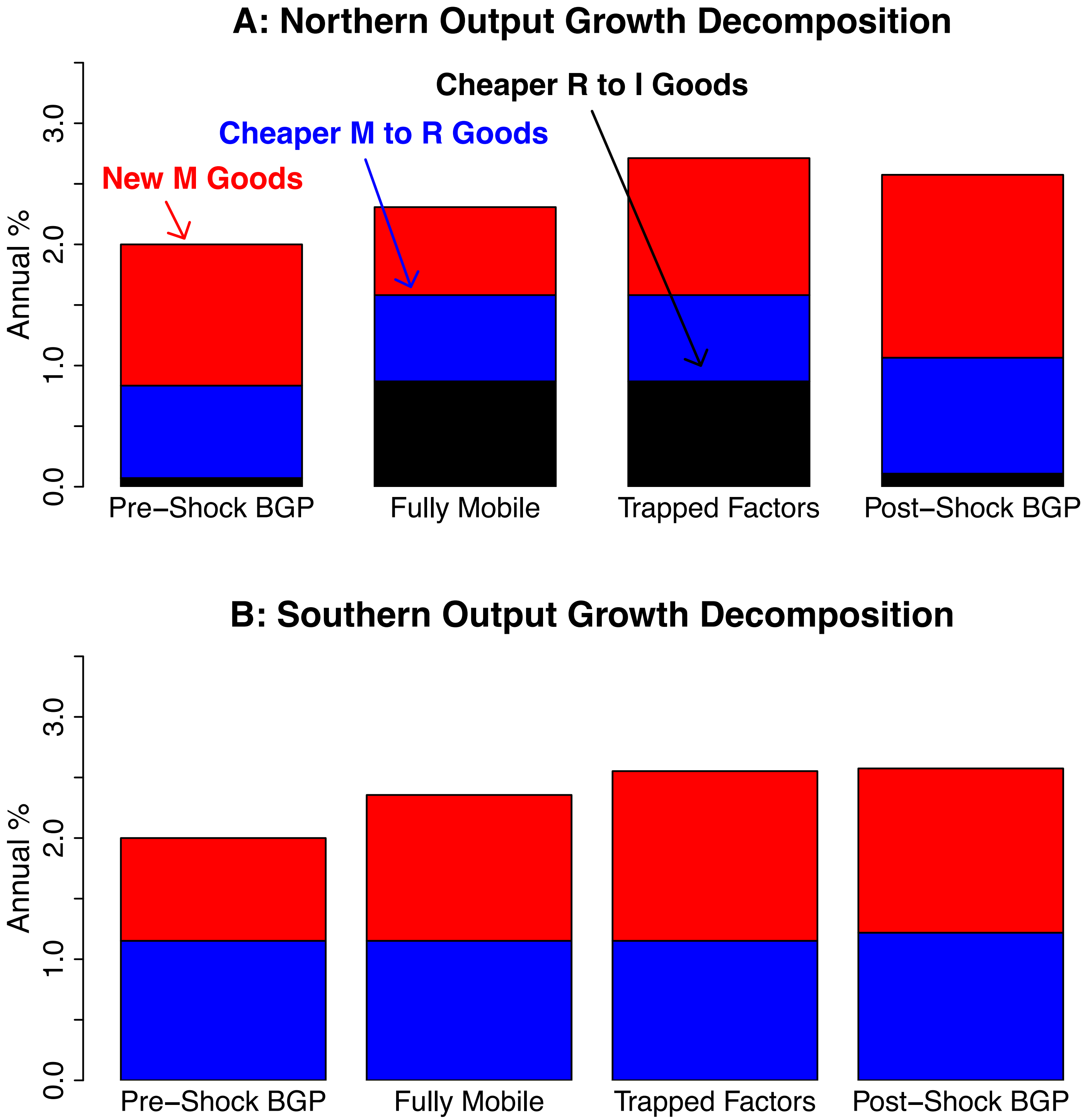

Figure 10: Price and Variety Contributions to Output Growth

Note: The figure displays decompositions of Northern output growth (top panel) and Southern output growth (bottom panel). The height of the bars correspond from left to right to output growth in the pre-shock balanced growth path, period 1 along the Fully Mobile transition path, period 1 along the Trapped Factors transition path, and the post-shock balanced growth path. Each bar contains three sections. The bottom black area “Cheaper R to I Goods” reflects the conversion of domestic R goods to lower-price imported I goods. The middle blue section labelled “Cheaper M to R Goods” reflects the conversion of previously monopoly protected M goods to off-patent R goods. The top section in red labelled “New M Goods” reflects new varieties of M goods. In the Southern economy the price of R and I goods is the same, so the bottom section is absent.

Table 4: Robustness of Welfare Results					
		Northern Gains		Southern Gains	
Intuitive Description	Parameter	TF	FM	TF	FM
Higher Discounting	$\beta = 1/1.04$	9.3	7.9	8.5	7.0
Lower Discounting	$\beta = 1/1.01$	66.6	61.6	64.1	59.1
More Congestion	$\eta = 0.5$	23.6	22.1	22.9	21.3
Higher Risk Aversion	$\sigma = 2.0$	23.8	18.8	23.3	18.3
Lower Risk Aversion	$\sigma = 1.5$	24.8	20.7	23.8	19.7
Less Curved Innovation Cost	$\rho = 0.6$	31.7	28.7	29.9	27.0
More Curved Innovation Cost	$\rho = 0.4$	20.1	17.6	18.9	16.4
Lower Labor Share	$\alpha = 0.5$	21.8	19.1	19.4	16.8
Higher Labor Share	$\alpha = 0.7$	26.4	23.5	25.2	22.3
Baseline	–	25.6	22.8	24.1	21.3

Note: The first column reports an intuitive description of the robustness check experiment. The second column records the parameter value varied from our baseline parameterization. The third and fourth columns report the consumption equivalent welfare gains from trade liberalization in the Northern economy in the Trapped Factors (TF) and Fully Mobile (FM) cases. The fifth and sixth columns report the consumption equivalent welfare gains from trade liberalization in the Southern economy in the Trapped Factors (TF) and Fully Mobile (FM) cases. The baseline parameterization features parameter choices of $\rho = 0.5$, $\alpha = 0.667$, $\beta = 1/1.02$, $\sigma = 1.0$, and $\eta = 1.0$. For each alternative experiment, we recalibrate the magnitude of the trade shock to match the observed import liberalization targets in Table 2.

from trade are small, moving from a pre-liberalization contribution of around 7 basis points of Northern growth to around 10 basis points post-liberalization. However, immediately after liberalization, a surge of imported I varieties in the North increases the contributions of price gains due to lower-cost imports to around 0.9 percent in both the Fully Mobile and Trapped Factors economies. In all cases, the remainder of growth is close to evenly split between purely dynamics gains from new M goods varieties and lower prices as monopoly patent protection expires. The relative importance of new varieties vs the expiration of patent-based markups is similar across the Northern and Southern economies, although no direct price gains due to lower-cost imports exist in the Southern case.

The decomposition in this section confirms that the dynamic effects from new varieties each period are dominant for our quantitative results.

5 Extensions and Robustness

In this section we discuss some extensions and the robustness of our results to various alternative assumptions and calibrations.

5.1 Robustness of Numerical Experiment

The qualitative effect of trade liberalization on growth, and the boost of innovation from the trapped factors mechanism, are quite robust to alternative parameterizations. To demonstrate this we vary parameter values and consider the impact upon the variety growth rate in the Trapped Factors transition in Figure 11. In each case, the transition path is recomputed after recalibrating the model with the new parameterization to match the trade liberalization targets in Table 2 which were also targeted in the baseline calculation. As Figure 11, reveals, in none of these cases is the pattern or magnitude of variety growth dynamics along the transition qualitatively changed.

In Table 4 we focus on welfare magnitudes, presenting Northern and Southern gains from liberalization in both the Fully Mobile and Trapped Factors cases for each parameter change experiment. Each row results from a distinct parameter change and recalibration of the trade shock within the model. The welfare gains vary in interesting ways. Outside of the quite mechanical differences in welfare gains due to largely implausible differences in discounting of future gains from growth in the first two rows, the single most crucial parameter in our experiments is ρ, the elasticity of innovation output to R&D expenditures and governs the curvature of the innovation cost function. For more curved innovation cost functions, resources channeled to R&D either as a result of a more attractive Southern market or the surplus of trapped factors within firms create a smaller increase in innovation or patenting, reducing the growth and welfare impacts of liberalization. By choosing our baseline value of $\rho = 0.5$ to match the empirical evidence on patenting at firms in response to R&D tax incentives (in Bloom, et al. 2013) or in a dynamic panel setting (Blundell et al., 2002), we discipline our macro results with micro variation.

To summarize, variety growth dynamics vary little across a range of recalibrations of the model, and together Figure 11 and Table 4 reveal that our central finding of potentially large dynamic welfare gains from trade is quite robust.

5.2 Semi-endogenous Growth

As discussed above, Jones (1995a) argues for an alternative innovation production function. We have been using $M_{ft+1} = (Z_{ft})^{\rho} A_t^{1-\rho}$, but an alternative is to use an exponent less than $1-\rho$ on $A_t^{1-\rho}$ following Jones' semi-endogenous approach. In such models, steady-state growth no longer depends on the level of human capital but instead on the growth of human capital. In Appendix D, we fully re-derive all the implications for long-term growth from such a model and numerically compute transition paths in this case, allowing for growth in human capital. Reasonably calibrated transition dynamics are extremely persistent, and long-run differences between our baseline model and the semi-endogenous growth model are heavily discounted into the future. The two model assumptions therefore deliver remarkably similar welfare results.

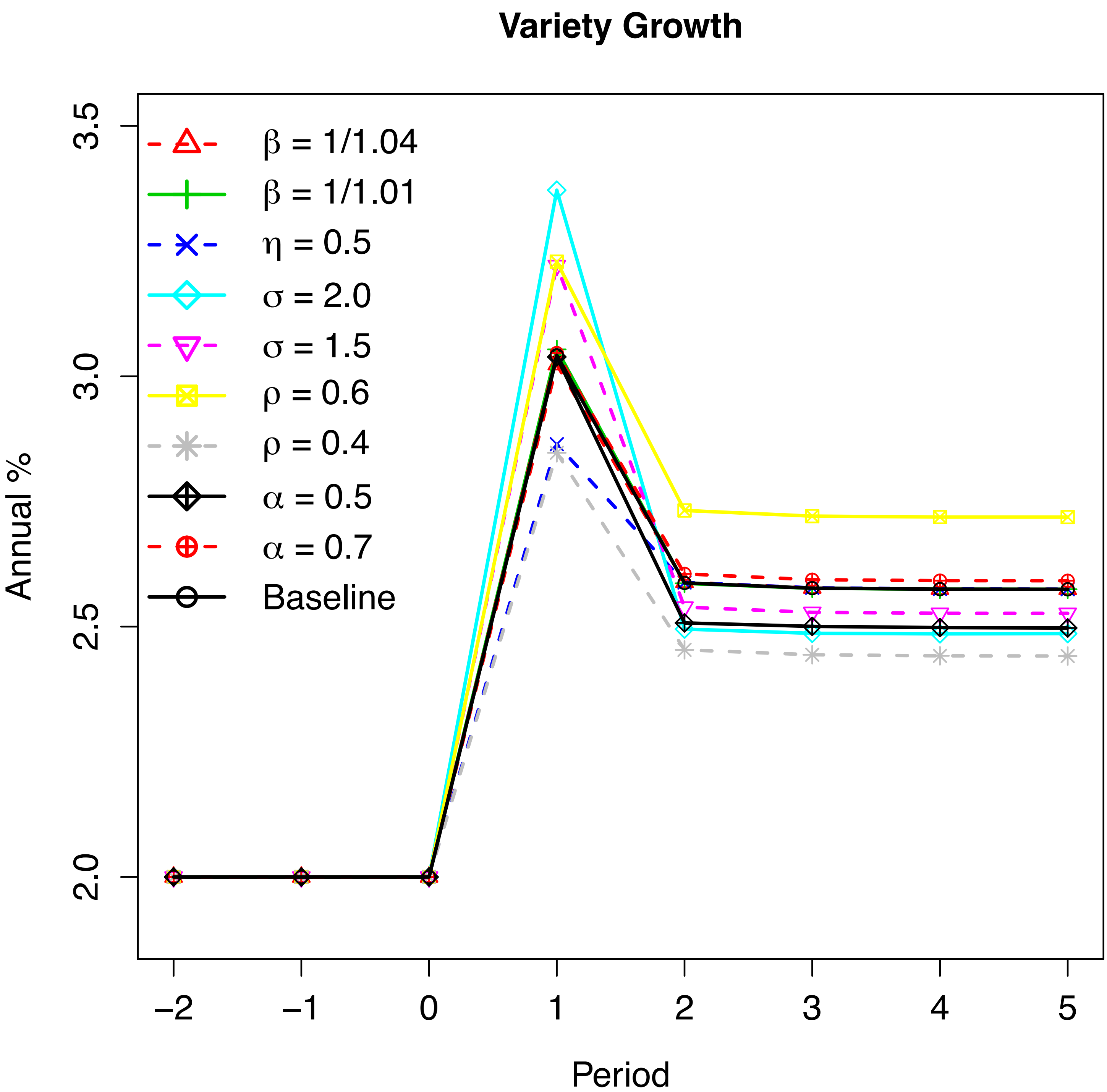

Figure 11: Trapped Factors Transition Dynamics are Robust

Note: The figure displays the Trapped Factors transition path in response to a permanent, unanticipated trade liberalization from policy parameter ϕ to $\phi' > \phi$, which is announced in period 0 to become effective in period 1. All plotted parameterizations of the model vary the parameter indicated in the legend, starting from the Trapped Factors calibration described in the text. Then, for each experiment with a new parameter value, the size of the trade shock is recalibrated to match the trade and growth target values as in the baseline exercise.

5.3 R&D Congestion Effects

Another concern with our baseline model is that R&D could have cross-firm congestion effects from research duplication or patent races. In an extension discussed in detail in Appendix E, we also introduce a model parameter η which allows for R&D congestion externalities. η flexibly nests our baseline case of no congestion externalities, ($\eta = 1$), but also allows for intermediate degrees of congestion all the way to the extreme case of full externalization of R&D costs ($\eta = 0$).

Empirical evidence suggests that these congestion effects are not large in the economy as a whole. Bloom et al. (2013b) estimate congestion effects from a large sample of US firms and find them to be statistically insignificant (i.e. $\eta = 1$).[9] Consequently, we have chosen to omit R&D cost externalities from the baseline model. For completeness, however, we also consider the intermediate case of $\eta = 0.5$ in Figure 11. In this case, congestion externalities dampen the magnitude of the short-term growth boost from trade. The dampening effect is not large, however, and the long-run growth effect remains the same.

5.4 Southern Innovation

Our construction of the baseline model above assumes that no innovation occurs in the Southern economy. While supported by low non-OECD patenting rates in the data, such an assumption is clearly strong and potentially odds with arguments presented in papers such as Puga and Trefler (2010) that Southern innovation is quite meaningful. So in Appendix F we extend the model to incorporate innovation of new varieties by Southern intermediate goods firms. To match low non-OECD patenting rates in the data, we allow for and calibrate lower relative productivity in innovation in the South. As discussed in more detail in Appendix F, the presence of Southern innovation implies that import ratios in the North are less sensitive to trade liberalization, requiring a larger liberalization shock to match the observed increase in low-cost import penetration in the North. Although the dynamic patterns are very similar, the larger required shock with Southern innovation implies that the baseline results above conservatively report the potential long-term dynamic benefits from trade liberalization. In particular, growth rates in the economy with Southern innovation increase from 2.0% to 3.1% in the long-term, which can be compared to the increase from 2.0% to 2.6% observed in the baseline environment without Southern innovation.

5.5 Other Effects of Trade with China

Trade between OECD countries and low-wage countries like China can have a large number of effects in addition to the ones we consider. We focus on its impact on the incentives for developing new goods because of the sheer potential scale of the dynamic gains from trade.

The most important potential offset to these gains, however, might come from the labor market.

[9] See Table IV of Bloom et al. (2013b).

Our model, like many others in trade, abstracts away from the unemployment and wage or other losses that may arise as workers are reallocated. Empirical work by Pierce and Schott (2016), Autor and Dorn (2013) and Autor et al. (2013) suggests that these dislocation effects can be substantial. There may be long-run effects on inequality through Heckscher-Ohlin factor price equalization effects or imperfect labor markets. Helpman et al. (2010) show how trade may increase steady state unemployment and wage inequality by making the exporting sector more attractive in a search theoretic context, with some evidence for the theory in Helpman et al. (2017). Finally, a range of labor adjustment frictions in dynamic analyses in Dix-Carneiro (2014), Artuç et al. (2010), Caliendo et al. (Forthcoming), and Traiberman (Forthcoming) suggest that occupational, regional, or industry switching costs for workers may prolong trade adjustment or result in pronounced differences across winners and losers.

By contrast, when our adjustment costs trap factors of production inside a firm, an unexpected increase in low-wage imports will cause losses that must be shared between the workers and the equity holders of an affected firm. We do not model how these losses are shared, so that in effect our approach is equivalent to making the assumption that there is a perfect insurance market among all residents in the North. To be sure, other types of adjustment costs could reduce welfare by making unemployment worse or exposing people to new uninsured risks. But as our analysis shows, in endogenous models of growth, it does not immediately follow that adjustment costs by necessity reduce the gains from trade.

5.6 Anticipation Effects

We have modeled the trade shock as being unexpected to firms. Although events such as China's WTO accession were of course partially anticipated, there was some surprise as negotiations were fraught. Moreover, in the entire European Union the liberalizations with China were temporarily reversed due to a political backlash.

To the extent that a shift from ϕ to ϕ' is announced in anticipated, agents will change their behavior. In particular there will be a disincentive to invest in trapped factors because the firm anticipates the liberalization. Hence, Northern firms will start shifting into innovative activities prior to the liberalization. The transition dynamics will change even though the long-run post-transition growth rates will remain the same. These considerations also demonstrate why a policymaker cannot engineer a larger short-run effect from trade by increasing adjustment costs. Increasing firing costs, for example, will certainly make factors more trapped, but it would itself signal impending liberalization and undue the desired innovative effect.

5.7 Patent Length vs. Adjustment Cost Horizon

Embedded within our analysis is an assumption that the model period, 10 years in our calibration, represents both the monopoly protection period and the period over which factors are trapped.

While this is not an unreasonable assumption given large empirical estimates of adjustment costs,[10] it is clearly very stark and worth exploring.

Allowing asset and monopoly lengths to differ would considerably complicate our analysis. However, we can consider the impacts qualitatively by examining the two potential cases arising from delinking the monopoly horizon (T^M) years, from the adjustment cost horizon (T^A). First, if $T^A > T^M$, then adjustment-cost induced periods of immobility are longer than monopoly protection. Trapped inputs would be used for the innovation of multiple cohorts of new varieties, which would likely not change the results qualitatively.

In the alternative case of $T^A < T^M$, pre-innovated cohorts of on-patent varieties may exist within firms at the time of a trade shock. These pre-existing monopoly varieties would offer an alternative substitution possibility into which trapped resources could be directed instead of innovation. This would reduce the innovation boost induced by our trapped factors mechanism, but on the other hand it would also reduce the welfare loss from monopoly markups. Hence, the net impact on welfare is ambiguous.

6 Conclusion

In this paper we present a new general equilibrium model of trade with endogenous growth that allows factors of production to be temporarily trapped in firms due, for example, to input specificity. This trapped factors model allows us to rationalize why in the face of an import shock from a low-wage country like China, incumbent firms in the affected industry may innovate more, as the firm-level micro-data suggests, even during a period of reduced demand.

The force behind this pattern in our model is a fall in the opportunity cost of R&D caused by a fall in the shadow cost of these trapped factors. The model also contains the more standard theoretical mechanism from the literature on trade and growth, whereby integration increases the profits from innovation.

We calibrate the model and provide an illustrative numerical experiment to compute the effects of a trade liberalization of the magnitude we observed in the decades bracketing China's accession to the WTO, 1994-2014. We find a substantial increase in welfare from such trade integration: a consumption equivalent increase of the order of 26% and a permanent increase in growth of around 0.6%. Around a tenth of the welfare gains are due to our trapped factors mechanism. However, the short-term impact of trapped factors is large, contributing an additional 0.4% to growth in the immediate aftermath of liberalization. Such short-term impacts are likely important at a policymaking horizon.

Note that the dynamic gains from trade in terms of growth or welfare depend entirely upon

[10]Capital and labor adjustment costs are typically estimated at between 10% to 50% of the lifetime cost of the assets (Bloom, 2009) making these long–term investment similar to intellectual property protection. Also, while patent lengths vary between 15 to 20 years, effective patent lengths are typically shorter due to imitation, processing lags, and imperfections in enforcement.

increased profits that innovators in the North can earn from sales in the South. In this sense, the model ratifies the increasing attention that trade negotiators are devoting to non-tariff barriers that might limit a foreign firm's ability to earn profits from a newly developed good. We have seen this already in the TRIPS agreement under the WTO, and better protection of intellectual property rights was also reported to be a central goal in the US approach to the negotiations leading up to the now-defunct Trans Pacific Partnership. If this is where the largest welfare gains lie, this is where trade agreements can have their biggest effects.

As noted in the introduction, there are many ways in which the modeling framework could be extended and made more realistic. We briefly touch on some additional potential avenues for exploration here. First, we have abstracted from "catch-up" in which growth rates in the South are higher than in North due to imitation or input accumulation. We did this in order to focus on welfare benefits in the North from loosened trade restrictions alone. Second, we focus on the impact of North-South integration rather than North-North integration. This was motivated by evidence that the pro-innovation effects in the North were far stronger when trade barriers against the South were relaxed compared to richer countries, but an extended framework along say the lines of Aghion et al. (2005) could allow for Schumpeterian and "escape competition" effects due to within-OECD liberalization. Third, a more careful analysis of the labor market and uninsured risk could offer an important offset to the effects that we identify. Although we have gone beyond steady states to look at transition dynamics we have, as is standard, abstracted away from distributional changes. Workers may suffer wage losses and unemployment if we introduce frictions in the labor market. These do seem to matter empirically, and more work needs to be done in the future to incorporate such effects in quantitative theory models (Harrison et al., 2011; Pessoa, 2016).

The main message of our paper is that liberalized trade with the South can have substantial benefits for the North and the entire world because it induces more innovation. China alone accounts for almost half of the gains we identify. Because dynamic or innovation-based benefits remain less visible than the losses that firms and workers can face from an unexpected increase in trade, and because some of the long-term effects we document can take decades to be realized, it is as important as ever for economists to understand why it may be so important to pursue and protect the gains from trade.

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